

**Factors affecting the rehabilitation
and release of adult badger
(*Meles meles*) casualties**

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Surgery**

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Declaration

I declare that the research reported in this thesis has been carried out by me at the Royal (Dick) School of Veterinary Studies, University of Edinburgh, and help that was received for any part of the work has been duly acknowledged. I believe that the contents of this thesis are wholly original, except where references are made. The work reported in this thesis has not been presented for any other degree, postgraduate diploma or professional qualification.

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'The kindly Badger thrust them down on a settle to toast themselves at the fire, and bade them remove their wet coats and boots. Then he fetched them dressing-gowns and slippers, and himself bathed the Mole's shin with warm water and mended the cut with sticking-plaster till the whole thing was just as good as new, if not better. In the embracing light and warmth, warm and dry at last, with weary legs propped up in front of them, and a suggestive clink of plates being arranged on the table behind, it seemed to the storm-driven animals, now in safe anchorage, that the cold and trackless Wild Wood just left outside was miles and miles away, and all that they had suffered in it a half- forgotten dream.' (Wind in the Willows, Kenneth Grahame, 1908)

To Pauline Kidner of Secret World Wildlife Rescue.
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Abbreviations

AFB	acid-fast bacteria
ALB	albumin
ALKP	alkaline phosphatase
ALT	alanine aminotransferase
AMYL	amylase
BCG	bacillus Calmette-Guérin
BP	British pharmacopoeia
bTB	bovine tuberculosis
BUN	blood urea nitrogen
BVA	British Veterinary Association
BWDA	British Wildlife Disease Association
BWRC	British Wildlife Rehabilitation Council
Ca	calcium
CDV	canine distemper virus
CHOL	cholesterol
Cl	chloride
CNS	central nervous system
CPV	canine parvo virus
CREAT	creatinine
CSL	Central Science Laboratory (now part of FERA)
CT	computed tomography
DEFRA	Department of Environment Food and Rural Affairs (formerly MAFF)
DOT	direct observation of therapy
DV	dorso-ventral
EDTA	ethylenediaminetetraacetic acid
ELISA	enzyme linked immunosorbent assay
EWDA	European Wildlife Disease Association
FERA	Food and Environment Research Agency (formerly CSL)
GGT	gamma-glutamyl transferase
GLOB	globulin
GLU	glucose

GPS	global positioning systems
Hb	haemoglobin
HIV	human immunodeficiency virus
IFN- γ	interferon gamma
ISG	Independent Scientific Group on cattle TB
IWRC	International Wildlife Rehabilitation Council
K	potassium
Kg	kilograms
MAFF	Ministry for Agriculture Fisheries and Food (now DEFRA)
MAPIA	multi-antigen print immunoassay
MCH	mean corpuscular haemoglobin
MCHC	mean corpuscular haemoglobin concentration
MCV	mean corpuscular volume
MRI	magnetic resonance imaging
MusHV-1	mustelid herpes virus-1
Na	sodium
NCCCC	National Collaborating Centre for Chronic Conditions
NFBG	National Federation of Badger Groups (now Badger Trust)
NHS	National Health Service
NSAIDS	non-steroidal anti-inflammatory drugs
OIE	World Organisation for Animal Health
OS	ordinance survey
OWCN	Oiled Wildlife Care Network
PCV	packed cell volume
PHOS	inorganic phosphorus
PPE	personal protective equipment
PPD	purified protein derivative
QVH	Quantock veterinary hospital
RBCT	randomised badger culling trial
RBC	red blood cell
RCVS	Royal College of Veterinary Surgeons
RSPCA	Royal Society for the Prevention of Cruelty to Animals

RTA	road traffic accident
RVN	registered veterinary nurse
SD	standard deviation of the mean
SOP	standard operating procedure
SWWR	Secret World Wildlife Rescue
TB	tuberculosis
TBIL	total bilirubin
TNF	tumour necrosis factor
TP	total protein
TST	tuberculin skin test
UCD	University College Dublin
UK	United Kingdom
USA	United States of America
VD	ventro-dorsal
VLA	veterinary laboratories agency
VHF	very high frequency
VSA	veterinary surgeons act
WBC	white blood cell
WCA	wildlife and countryside act, 1981
WDA	Wildlife Disease Association
WHO	World Health Organisation

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Abstract

Free-ranging wildlife casualties are commonly presented to veterinary surgeons who have a professional responsibility for their immediate care and welfare. This thesis reports why 123 badgers (*Meles meles*) were presented to a wildlife rescue centre and veterinary hospital in Somerset, and the factors influencing their release to the wild. The seasonality and demographics of admissions were greatly affected by the ecology of the badger. Common reasons for presentation included road traffic accidents and the presence of conspecific bite wounds. Clinical triage and diagnostic tests, including blood biochemistry and haematology and radiography, identified both primary and concurrent clinical problems. Bite wounds occurred most commonly in male animals found in buildings but only impacted upon release when present with another disease. *M. bovis* infection diagnosed in four badgers created potential zoonotic risks whilst the badgers were in captivity and ethical issues associated with potential disease transmission to cattle, although all were identified on clinical examination; none was released. Approximately one third of badger casualties were released after a period of veterinary treatment and rehabilitation, the remaining animals were euthanased for welfare reasons although a small number died unexpectedly; body condition score was the best prognostic indicator for release. This study provides information and guidance regarding the clinical examination, treatment and care of badgers presented to veterinary surgeons.

Chapter 1

Introduction and literature review

1.1 Wildlife rehabilitation in the United Kingdom

1.1.1 Reasons for treating wildlife

There are many reasons why veterinary surgeons become involved in the treatment and investigation of free-living wildlife species (Kirkwood, 2003; Cooper and Cooper, 2006). In some instances, indigenous wildlife species are treated because they are endangered and specific protection must be given when disease threats arise for example; vaccination of mountain gorillas (*Gorilla gorilla beringei*) in Central Africa against the human measles virus (Sholley, 1989), treatment of mountain gorillas in Uganda for sarcoptic mange (Kalema-Zikusoka *et al.*, 2002), treatment of bighorn sheep (*Ovis Canadensis*) in New Mexico for psoroptic mange (Lange, 1982), and treatment of disease and trauma in individual endangered bird species in New Zealand (Mullineaux, 2006) such as the vaccination of Kakapo (*Stringops habroptila*) against erysipelas (Gartrell *et al.*, 2005). In other cases, the scale of the disease epidemic is the more important reason for treatment rather than the rarity of the species involved, for example antitoxin usage in avian botulism outbreaks (Martinez and Wobeser, 1999; Rocke *et al.*, 2000; Wobeser, 2007).

The treatment of large groups of wild animals may also be carried out for public health reasons and zoonotic risk, such as the oral vaccination of red foxes (*Vulpes vulpes*) (Rupprecht *et al.*, 2001) and other species (Rosatte *et al.*, 2008) in the control of sylvatic rabies. The health of domestic livestock can be a reason to control disease in wildlife species through vaccination, for example in the control of tuberculosis (*M. bovis* infection) in Australian brushtail possums (*Trichosurus vulpecula*) in New Zealand (Corner *et al.*, 2002b), and potentially in badgers (*Meles meles*) in the United Kingdom (UK) (Lesellier *et al.*, 2006; Lesellier *et al.*, 2009a) and Ireland (Corner *et al.*, 2008b; Corner *et al.*, 2009).

The need to investigate and monitor wildlife for new and emerging infectious diseases affecting man and other species has been discussed on a Europe wide basis (Artois *et al.*, 2001), and the requirement for co-ordinated monitoring of wildlife diseases in the UK has been acknowledged (Sainsbury *et al.*, 2001). Much of the wildlife disease monitoring in the UK is carried out by the Veterinary Laboratories

Agency (VLA) Wildlife Disease Monitoring Program, which aims to detect reservoirs of potentially zoonotic diseases, diseases of livestock, and new pathogens and environmental pollutants (Duff, 2003). The British Wildlife Disease Association (BWDA) reports wildlife diseases to members through regular newsletters. Reports of disease across Europe and the rest of the world are disseminated through organisations such as the Wildlife Disease Association (WDA), European Wildlife Disease Association (EWDA) and the World Organisation for Animal Health (OIE).

The investigation of wildlife diseases is concerned primarily with populations rather than individual animals. The treatment of injury or disease in individual animals arises out of different concerns and needs from those reasons described above. One of the greatest arguments for the treatment of individual wildlife casualties, even when they are not endangered species, is to attempt to counter balance the negative actions of man on species demographics and individual animal welfare. This moral and ethical responsibility is most powerfully illustrated by large man-made catastrophes affecting many animals such as oil spills, where much has been learned about the treatment of such pollution on large numbers of seabirds (Wernham *et al.*, 1997, Mazet *et al.*, 2005), and marine mammals (Baker *et al.*, 1981). The same principles of 'addressing the balance' can be applied to the treatment of other casualties of man-made problems that occur on a smaller individual scale, for example in European hedgehogs (*Erinaceus europaeus*) 40% of deaths in individuals treated by wildlife rescue centres in the UK and the Netherlands arise from road traffic accidents (RTA), garden and pet injuries, poisoning and disturbance of local environments (Reeve and Huijser, 1999). In the UK there is strong public support for the treatment of wildlife casualties and their protection. Provision of such professional services generates a feel good factor for the veterinarian involved and a secondary public relations benefit to veterinary practices treating wildlife (Kirkwood, 2003; Cooper and Cooper, 2006). There is also an educational benefit to those dealing with wildlife casualties creating an environmental and conservation awareness (Wobeser, 2007; Vogelnest, 2008). For veterinarians, the treatment of non-endangered species may additionally develop skills then useful when presented with endangered species (Wobeser, 2007).

1.1.2 Veterinary treatment, rehabilitation and release of wildlife

1.1.2.1 Ethical and welfare considerations

In the UK, the Royal College of Veterinary Surgeons (RCVS) 'Guide to Professional Conduct' charges the veterinary surgeon with a legal obligation to provide emergency care, 'at least first aid and pain relief', to all species of animal including indigenous wildlife (RCVS, 2008). The British Veterinary Association (BVA) and Royal Society for the Prevention of Cruelty to Animals (RSPCA) 'Memorandum of agreement' further recommends that the emergency care or euthanasia of small mammals and wild birds brought to practices during normal surgery hours will be provided free of charge, although this agreement is not legally binding (BVA, 2008). The RSPCA contributes to the cost of out-of-hours call-out fees or visits to large mammals such as deer.

Balanced against such well-meaning human intentions, must be the need to avoid causing unnecessary suffering to animals brought into captivity through an inappropriate attempt to extend their natural life (Best and Mullineaux, 2003; Kirkwood, 2003). Several authors have debated the ethics and welfare of treatment of wildlife species (Cooper, 1989; Kirkwood and Sainsbury, 1996; Kirkwood, 2003; Cooper and Cooper, 2006) with all concluding that the welfare of the individual casualty should be the overriding consideration. Much less discussed or known are the ecological effects of the release of rehabilitated individuals and groups of animals on existing populations (Robinson, 2002), especially where animals are translocated (Griffith *et al.*, 1993; Wobeser, 2007).

Most wildlife care and rehabilitation is provided by lay people rather than veterinary surgeons and this may create emotional and philosophical, as well as veterinary, problems (Sikarskie, 1992).

1.1.2.2 Education of veterinarians and rehabilitators

An appreciation of the need to treat wildlife casualties correctly and educate those involved in their care has developed around the world in countries including Australia (Tribe and Brown, 2000; Vogelnest, 2008), United States of America (USA) (Miller, 2000), and New Zealand (Hunt, 2003). In the UK an interest in

wildlife rehabilitation has often arisen from the various Wildlife Trusts such as the Badger Trust, Bat Conservation Trust, British Hedgehog Preservation Society, and British Trust for Ornithology, although the main focus for these groups has remained conservation rather than the treatment of individual animals. Latterly, rehabilitators from these groups have formed the British Wildlife Rehabilitation Council (BWRC), which produces guidelines for rehabilitation (BWRC, 2007a, b) and collects data on species treated and release rates (Best, 1999; BWRC, 2000). The International Wildlife Rehabilitation Council (IWRC) offers training and publishes rehabilitation research in its journal.

Several textbooks have described the care of British wildlife (Cooper and Eley, 1979; McKeever, 1979), and more recently (Ruth, 1997; Stocker, 2005). Veterinary work in this specialised area has however, been limited and it has only been in the last decade that a textbook aimed specifically at veterinary surgeons in practice, rather than rehabilitators has been produced (Mullineaux *et al.*, 2003). Online resources are now available to veterinary surgeons (Bourne *et al.*, 2001) and several series of articles have been published in veterinary journals aimed specifically at the first opinion practitioner dealing with wild birds (Chitty, 2006a, b) and mammals, including badgers (Lewis, 1997a, b, c). Information for veterinary nurses has also been published (Gosden, 2004; Meredith *et al.*, 2008). A good working relationship between lay rehabilitators and their vets is an essential part of a successful rehabilitation and release programme and has been encouraged (Miller, 2000). Limiting factors for the success of treatment, rehabilitation and release of wildlife casualties include facilities, suitably trained personnel and funding (Best and Mullineaux, 2003; Wobeser, 2007). Although there is an argument that funds should not be diverted from habitat conservation projects to the care of casualties (Wobeser, 2007) there is no evidence that those who fund wildlife rescue work would donate elsewhere (P. Kidner, *pers. comm.*).

Recent developments in British wildlife care and rehabilitation have included the involvement and education of the general public in wildlife care such as in the Garden Bird Health initiative (Lawson *et al.*, 2008).

1.1.2.3 Rehabilitation and release of juvenile casualties

As the veterinary treatment and management of wildlife casualties has become more common, attempts have been made to assess the success of rehabilitation and release. Groups of artificially reared juvenile mammals and birds have provided an opportunity for monitoring the success of the release process, for example the post-release survival of reared birds of prey has been determined using leg band return data and radio-tracking. Return rates suggest the short-term success of release to be in the region of 37-75% across a range of species; tawny owls (*Strix aluco*) (Bennet and Routh, 2000; Leighton *et al.*, 2008; Griffiths *et al.*, 2010), barn owls (*Tyto alba*) (Fajardo *et al.*, 2000), western screech owls (*Otus kennecotti*) (Allbritten and Jackson, 2002), peregrine falcons (*Falco peregrinus*) (Sweeny *et al.*, 1997) and mallard ducklings (*Anas platyrhynchos*) (Drake and Fraser, 2008). Such studies are however limited by sample size and the methods of tracking employed (Griffiths *et al.*, 2010).

European hedgehogs (*Erinaceus europaeus*) are the UK mammal species seen most frequently in rescue facilities (Reeve and Huijser, 1999) and have most published data regarding rehabilitation. Several authors have reported survival rates in rehabilitated and released juvenile hedgehogs varying from good; 82% survival at six weeks post release (Morris, 1998), 77% survival at six weeks (Morris, 1997), 75% survival at five weeks (Morris *et al.*, 1993), to less successful rates; 33% survival at six weeks (Sainsbury *et al.*, 1996), 25% survival at eight weeks (Morris and Warwick, 1994). In some studies RTA and predation by badgers were given as the major reasons for losses (Sainsbury *et al.*, 1996; Morris, 1998). The release of juvenile pipistrelle bats (*Pipistrellus pipistrellus*) following rehabilitation also had variable success, from 0-100% over 2-10 night monitoring periods, these data were subsequently used to illustrate the benefits of pre-release fitness using flight cages (Kelly *et al.*, 2008).

The successful rehabilitation of dependent badger cubs is greatly influenced by blood testing protocols that attempt to ensure that the animals are free of *M. bovis* infection prior to release (SWWR *et al.*, 2003; Mullineaux, 2003b, 2007a, b, 2008). This is reviewed further below (1.12).

Release studies of juvenile animals often provide additional useful information for the rehabilitator and veterinarian, for example optimum weights have been suggested for the release of hedgehogs (Morris and Warwick, 1994) and optimal ratios of weight to size (Bunnell, 2002). Information regarding the success or otherwise of releases can also be used by others outside the rehabilitation process, for example to produce recommendations for road planners (Ramsden, 2003).

1.1.2.4 Treatment, rehabilitation and release of adult casualties

Groups of adult animals occasionally arise for rehabilitation, such as the hedgehogs moved from Uist to the British mainland in 2004. In this case the animals were shown to benefit from a period in captivity rather than being directly translocated to new areas, although few medical casualties were encountered (Molony *et al.*, 2006).

As described above, one of the occurrences of large numbers of wildlife casualties is following man-made disasters where birds and other animals become contaminated through oil or petroleum spills. The numbers of adult casualties involved in such instances provide for useful study of the methodology and success of their treatment, rehabilitation and release. Co-ordination between interested groups has allowed for strategic planning for future disasters (Mazet *et al.*, 2005). Improvements in care have resulted in release rates following decontamination improving from 0-5% in the 1970s to 60-75% in the late 1990s (OWCN, 2002). Despite such improvements post release survival can still be poor; in one study 70% of oiled guillemots (*Uria aalge*) died within the two weeks following release (Wernham *et al.*, 1997) and long-term survival post release is further hampered by chronic disease including reduced success of breeding (Jessup and Leighton, 1996; Newman *et al.*, 2003).

Little literature has been published regarding the successful release of adult casualties from a typical wildlife rescue centre. BWRC collated figures from wildlife rehabilitation centres suggested a release rate of 42% for all species and 31% for mammals (BWRC, 2000). Molony *et al.* (2007) reviewed the records of eight species, including badgers, from four RSPCA wildlife centres and found an overall release rate of 39% (+/-8%). Their main recommendation was that a proven triage process be adopted as recommended by other authors (Best and Mullineaux, 2003;

Vogelnest, 2008), enabling euthanasia of those casualties with a grave prognosis. Illness and injury were considered to be a more important indicator of the likelihood of success than other factors such as body mass. Occasionally, wildlife rehabilitation centres themselves act as a source of unusual diseases such as Tyzzer's disease in an otter (*Lutra lutra*) (Simpson *et al.*, 2008).

The future of wildlife rehabilitation may be determined by the Department of the Environment Food and Rural Affairs Wildlife Health Strategy (DEFRA, 2007), including possible legislation controlling rehabilitation facilities.

Badgers are one of the most studied British wildlife species not least because of their association with tuberculosis (*M. bovis*) infection in cattle. However, the volume of published information on treatment and rehabilitation is extremely limited.

1.2 Ecology of the badger relevant to its successful rehabilitation

1.2.1 Classification of the species *Meles meles*

Badgers are included in the family Mustelidae; small and medium mammals with the characteristics of long bodies on relatively short legs, five digits and musk glands. Other mustelids include otters (*Lutra*), martens (*Martes*) and the small mustelids (*Mustela*) such as stoats (*Mustela erminea*), weasles (*Mustela nivalis*), polecats (*Mustela putorius*), ferrets (*Mustela furo*), and American mink (*Mustela vison*). The subfamily Melinae (true badgers) contains six genera; *Meles* (Eurasian badger), *Arctonyx* (Asian hog badgers), *Mydaus* (Indonesian stink badgers), *Suillotaxus* (Palawan and Calamian Island stink badgers), *Taxidea* (American badgers) and *Melogale* (Asian ferret badgers). The honey badger (*Mellivora capensis*) is included in a separate subfamily Mellivorinae (Neal and Cheeseman, 1996; Delahay *et al.*, 2008). Skull characteristics have been suggested to separate the European badger (*Meles meles*) from other Eurasian badgers; the Asian badger (*Meles leucurus*) and the Japanese badger (*Meles anakuma*) with four subspecies of *Meles meles* (*meles*, *milleri*, *canescens* and *arcalus*, respectively) (Abramov and Puzachenko, 2006).

1.2.2 Distribution and population density

The Eurasian badger occurs across the Palearctic region, in all states of Europe west of the border with the former Soviet Union but is absent from arctic zones, high altitude areas, and some islands (Griffiths and Thomas, 1993). In Great Britain and Ireland badgers are absent only in regions over 500 m and most off-shore islands (Delahay *et al.*, 2008). Population densities are greatest in the south west of England and Wales, and the east of Ireland, with estimates over 1.2 animals per km² (Wilson *et al.*, 1997; Delahay *et al.*, 2008). The overall population of badgers in the UK has increased greatly over the last 20 years; in high-density study areas such as Woodchester Park and Wytham Woods populations have reached 25.3 adults per km² (Rogers *et al.*, 1997b) and 38 adults per km² (Macdonald and Newman, 2002) respectively. The population increase does not appear to correlate with improved badger protection or changes in habitat in all areas. Changing weather patterns, possibly resulting from climate change, have been considered a contributing factor (Macdonald and Newman, 2002). Regardless of overall density within an area, the spatial distribution of badgers appears to depend upon availability of resources (Kruuk and Parish, 1982; Palphramand *et al.*, 2007) and within areas of highest density there is evidence of constraints on further population growth (Cheeseman *et al.*, 1993; Rogers *et al.*, 1997a; Rogers *et al.*, 1997b; Macdonald and Newman, 2002).

1.2.3 Social structure and behaviour

1.2.3.1 Social groups

Badgers live in social groups of approximately six (range 2-23) adult animals, dependent on habitat, with availability of arable land being the greatest influencing factor (Delahay *et al.*, 2006a). Territory size of social groups ranges from 30 hectares in optimal habitat to 150 hectares in less ideal areas. Low badger population density and human disturbance of populations reduce the distinction of social group habitats. Territorial boundaries are marked by well worn paths and latrines shared by several social groups (Roper *et al.*, 1993). Woodland, hedges and stone walls are selected for latrine areas, although the larger occurrence of grassland areas means that most latrines are actually within grassland areas (Delahay *et al.*, 2007b). Neighbouring

social groups recognize and tolerate other groups but individual badgers show negative behavioural responses such as aggression to alien badgers from outside their immediate habitat areas, especially during the breeding season (Palphramand and White, 2007).

Male animals show a more active role in defining territory and have larger ranges than females (Roper *et al.*, 1993) but badgers have no spatial awareness of areas outside their own and neighbouring social groups (Bodin *et al.*, 2006). A positive correlation has been found between ranging behaviour and *M. bovis* infection in badgers (Garnett *et al.*, 2005). Movement of male badgers between social groups is evident through paternity testing of cubs (Evans *et al.*, 1989; Woodroffe, *et al.*, 1995). Marking of territory is through scent from subcaudal glands, anal glands, sweat and sebaceous glands and interdigital scent glands (Neal and Cheeseman, 1996) and urine and faeces (Delahay *et al.*, 2008). Territorial marking by individuals can be illustrated using faecal DNA typing (Frantz *et al.*, 2006). Territorial disputes between badgers resulting in wounding are discussed below (1.4).

1.2.3.2 Setts

Badgers live in setts comprising a network of connecting chambers and burrows with typically 3-10 (range 1-80) openings. Sett entrances frequently have signs of nesting activity such as soil heaps and discarded bedding material (Neal and Cheeseman, 1996; Delahay *et al.*, 2008). Social groups usually have one 'main' sett and several smaller 'outlier' setts (Neal and Cheeseman, 1996). 'Annex' and 'subsidiary' setts have also been described, differentiated from other sett types by their size and pathway connections to the main sett (Thornton, 1988; Neal and Cheeseman, 1996). Main setts are larger in terms of area and volume than other setts, and contain more chambers, nest areas and latrines and may allow members of the social group to avoid one another underground, especially when breeding (Roper, 1992). Ideal environments for sett construction have been described; for example in Wytham woods sandy, well-drained soil, situated on north west-facing, convex and moderately inclined slopes at moderate altitude (Macdonald *et al.*, 2004c). However, suitability of environment does not appear to be a limiting factor in the increase in local density of a badger population (Macdonald *et al.*, 2004c).

Badgers in urban and suburban environments use fewer setts than those social groups in neighbouring rural areas, however sett densities can be high and may result in sett-related problems such as damage to gardens and homes (Davison *et al.*, 2008). Sett location and badger population density in urban areas depends upon habitat, slope of the ground and level of human activity, with badgers generally preferring intermediate human population density (Huck *et al.*, 2008).

1.2.3.3 Activity

Badgers are crepuscular and nocturnal animals. Emergence from setts is usually at dusk in the spring and summer (May to August) and after darkness at other times of year. Activity is greatly reduced in the winter months (November to February) especially in the northern areas of the UK (Delahay *et al.*, 2008). Food availability (Neal and Cheeseman, 1996), environmental conditions (Cresswell and Harris, 1988), and human activity (Lindsay and Macdonald, 1985) may also affect the time of emergence. Age of animals also affects the time of emergence, cubs usually emerging first (Neal and Cheeseman, 1996). Urban badgers and those influenced by human activity tend to emerge after dark. Diurnal activity, usually related to foraging, is not uncommon during the summer (Neal and Cheeseman, 1996).

Badgers have been shown to use farm buildings as resources for both refuge and foraging in England (Cheeseman and Mallinson, 1981; Garnett *et al.*, 2002; Roper *et al.*, 2003; Ward *et al.*, 2008; Tolhurst *et al.*, 2009), and to a lesser extent in Ireland (Sleeman and Mulcahy, 1993; Sleeman *et al.*, 2008). Male animals have been shown to frequent farm buildings more commonly than females (Tolhurst *et al.*, 2009). Visits by badgers to farms are more frequent when rainfall is low (Garnett *et al.*, 2002; Tolhurst *et al.*, 2009) and temperatures high in the spring and summer months (Tolhurst *et al.*, 2009). Conversely the use of domestic buildings by badgers has been described in the Czech Republic to occur more frequently in the winter than summer months (Pavlačik *et al.*, 2004). An association between frequency of visits to farm buildings and infection rate with *M. bovis* in badgers has been reported (Cheeseman and Mallinson, 1981). Contamination of cattle bedding and feed by badger faeces, and direct contact between the species, may increase the risk of *M. bovis*

transmission (Garnett *et al.*, 2002; Garnett *et al.*, 2003; Ward *et al.*, 2008; Tolhurst *et al.*, 2009). Biosecurity measures to restrict access by wildlife to farm buildings are rarely undertaken by farmers even in areas of herd breakdowns as a result of *M. bovis* infection (Ward *et al.*, 2008). Electric fencing has proven successful in excluding badgers from farms buildings (Tolhurst *et al.*, 2008).

1.2.4 Diet and feeding

Badgers are opportunist omnivores, eating a wide variety of plant and animal matter including earthworms (*Lumbricus terrestris*), fruit and insects (Roper, 1997), small mammals and birds (Hounsome and Delahay, 2005). Diet may show seasonal fluctuation dependent upon availability of food types such as insect larvae (Cleary *et al.*, 2009). Earthworms have been described as being the most important foodstuff in badger diets (Kruuk and Parish, 1985; Neal, 1988) although their intake can be very variable (Roper, 1997). A weak correlation between earthworm density and badger densities, probably results from the wide availability of earthworm-rich grazed grassland suitable for badger foraging (Muldowney *et al.*, 2003). The bodyweight of badgers and weight gain during the summer and autumn is positively correlated to available permanent pasture and ley grassland (Delahay *et al.*, 2006a). Body weight influences reproductive success (Cresswell *et al.*, 1992). No feeding hierarchy has been shown within social groups or between neighbouring groups (Macdonald *et al.*, 2002). Badgers may take advantage of farm feeds made available in troughs (Garnett *et al.*, 2003; Roper *et al.*, 2003) and from open feed stores (Garnett *et al.*, 2003; Roper *et al.*, 2003; Ward *et al.*, 2008; Tolhurst *et al.*, 2009) where a preference for cattle concentrates ('cake') has been shown (Tolhurst *et al.*, 2009). The risk of transmission of *M. bovis* infection to cattle associated with such badger feeding activity is discussed below (1.12).

1.3 Biology of the badger relevant to its successful rehabilitation

1.3.1 Size and weight

Badgers are the largest British carnivore. Badgers are opportunist omnivores (1.2.4). Their weight is dependent upon age, sex and seasonal food availability (Kruuk and

Parish, 1983; Clifton-Hadley *et al.*, 1993). Male animals have longer head and body measurements than females (average 753mm, range 686-803mm; 724mm, 673-787mm, respectively), and are heavier (average 11.6kg, range 9.1-16.7kg; 10.1kg, 6.6-13.9kg, respectively) (Neal, 1977; Delahay *et al.*, 2008).

The seasonality in badger weight follows the availability of food, being lowest in the summer and greatest in the autumn (Kruuk and Parish, 1983; Cheeseman *et al.*, 1987; Cresswell *et al.*, 1992; Clifton-Hadley *et al.*, 1993; Delahay *et al.*, 2006a). Weights increase in the autumn months associated with fat deposition before winter (Zalewski *et al.*, 2007), with measurement of perirenal and omental adipose tissue showing similar seasonal trends to overall body mass (Cresswell *et al.*, 1992). Female animals may show a greater loss of weight in the summer months than males (Cresswell *et al.*, 1992) caused by social, reproductive and density-dependent effects. A correlation has been shown between mild winters and heavier body weights of badgers in January (Macdonald and Newman, 2002).

Mean badger body weight is significantly heavier for badgers occupying territories with setts in sandy soils, situated on north west-facing slopes (ideal setts), than those with less optimal sett characteristics (Macdonald *et al.*, 2004c). Population density adversely affects body condition and weight (Rogers *et al.*, 1997a; Tuytens *et al.*, 2000b) with an increase in group size resulting in a decrease in body weight of breeding female animals during the autumn and winter, and male animals in the summer (Rogers *et al.*, 1997a).

Tuberculosis (*M. bovis* infection) has been shown to result in weight loss and emaciation in those animals clinically affected (Clifton-Hadley *et al.*, 1993) (1.12).

1.3.2 Anatomy

Although post-mortem examination of badgers is not usually carried out in veterinary practices for health and safety reasons, veterinarians still benefit from knowledge of the normal anatomy of badgers for clinical examination and imaging techniques such as radiography and ultrasonography.

Badgers have short limbs similar to those of chondrodystrophic breeds of dog, with normal antebrachial characteristics such as cranial bowing of the distal radius, carpal valgus and lateral rotation of the distal limbs (Mullineaux, 2003a). There are five full digits with non-retractile claws that are often long, especially on the front feet. The skull has a prominent interparietal ridge that develops with age and is largest in adult male animals (Neal and Cheeseman, 1996; Delahay *et al.*, 2008). The eyes and ears are small, with hearing and smell being the predominant senses. The coat appears grey due to a melanin band within the dorsal and lateral guard hairs. There is no colour difference between the sexes. Badgers moult from the spring into the summer months, the under coat shedding and re-growing first followed by the guard hairs. Colour variations have been identified; albino, erythristic, melanistic and intermediate variants (Neal and Cheeseman, 1996; Delahay *et al.*, 2008). The skin is mobile and tougher than that of dogs (Neal and Cheeseman, 1996). In the summer and autumn months subcutaneous fat is laid down allowing periods of relative inactivity in the winter (Zalewski *et al.*, 2007). Badgers have subcaudal scent glands as well as anal glands, both are involved in territorial marking. Badger intestines are longer than those of the fox, with a mean length of 5.36 m and lack a caecum (Delahay *et al.*, 2008). The badger pancreas is three lobed, with two cranial lobes and a smaller caudal lobe; there are two pancreatic ducts (Ozdemir, 2005). Although fat conservation has been described (Zalewski *et al.*, 2007) badgers do not appear to conserve protein well during periods of food shortage (Delahay *et al.*, 2008). A basic metabolic rate of 500 Kcal (*ca.* 2000KJ/day) per day has been suggested (Domingo-Roura *et al.*, 2001).

1.3.3 Dentition

Normal badger dentition is described in several texts (Neal and Cheeseman, 1996; Delahay *et al.*, 2008). Variations in premolar number have been reported, with the first premolar either vestigial or absent (Neal and Cheeseman, 1996). In a study of badger skulls 94% of animals had at least one vestigial tooth (Hancox, 1988a). Supernumerary molars and premolars have also been described (Fullagar *et al.*, 1959; Hancox, 1988a). Deciduous dentition has been reported to erupt from 4-6 weeks (canines, premolars then molars) and permanent teeth from 10-16 weeks (Neal and Cheeseman, 1996).

The use of dentition for age determination has been reviewed (Hancox, 1988b; Harris *et al.*, 1992; Delahay *et al.*, 2008). Growth rings (annuli) in sectioned teeth were considered as a method of ageing badgers when tibial growth plate closure was delayed in some individual animals (Ahnlund, 1976). The use of annuli was however subsequently shown to have limited accuracy, especially in certain geographical areas where rings were indistinct, such as the south west of England (Ahnlund, 1980). Tooth wear was suggested as a useful method of ageing adult badgers in the field (Hancox, 1988c), but the validity of this finding has been questioned by others (da Silva and Macdonald, 1989). Harris *et al.* (1992) compared molar tooth wear, in particular that of the last molar, with badger skulls of known age. Molar wear was found to provide a reasonably accurate approximation of badger age especially in younger animals. For this reason classification of animals as ‘cub’, ‘yearling’ and ‘animals in their third year or older’ have been considered adequate for field research and in order to minimise errors (Cresswell *et al.*, 1992; Harris *et al.*, 1992). Dental cares have been reported in badgers (Andrews and Murray, 1974).

1.3.4 Reproduction

There is an equal ratio of male to female in cubs (Rogers *et al.*, 1997b; Macdonald and Newman, 2002; Dugdale *et al.*, 2003) and some studies have suggested this parity remains within populations over time (Macdonald and Newman, 2002), whilst other studies suggest that populations become increasingly female-biased with age (Rogers *et al.*, 1997b). Good body condition of sows, early implantation of embryos, and years with large cub cohorts have all been suggested as factors influencing a bias of male cubs born (Dugdale *et al.*, 2003).

Male badgers mature at 12-15 months (range 8-24 months) whilst females usually ovulate for the first time in the spring of their second year, at 12-15 months old (range 9-20 months) (Delahay *et al.*, 2008). Mating occurs year-round with a peak between February and May when mature sows return to oestrus after cubbing and young animals have their first oestrus. A second smaller peak occurs during autumn in late maturing yearlings and those sows that failed to conceive in the spring (Cresswell *et al.*, 1992). There is evidence that a second successful mating may also

occur in females that have already conceived but not yet implanted embryos (Yamaguchi *et al.*, 2006). Implantation of embryos in the bicornate uterus is delayed following conception in most cases and usually occurs in December (Delahay *et al.*, 2008). Implantation is affected by both photoperiod (on a timescale of months) and body condition (on a timescale of days) (Woodroffe, 1995). True gestation lasts 6-7 weeks with the majority of cubs born in February (Neal and Cheeseman, 1996). Litter size is usually between one and five cubs (Neal, 1977; Neal and Cheeseman, 1996).

Within social groups there is a high degree of relatedness and evidence of polyandry (Domingo-Roura *et al.*, 2003; Dugdale *et al.*, 2007; Dugdale *et al.*, 2008). Up to half of paternities however, may be from outwith the sett, usually from neighbouring groups that show similar genetic spatial clustering (Evans *et al.*, 1989; Woodroffe, *et al.*, 1995; Dugdale *et al.*, 2008).

Not all mature animals successfully breed each year; in one study it was estimated that between 58 and 90.2% of adult females fail to breed (Rogers *et al.*, 1997b) and in another study that only 27% of adult males and 31% of adult females bred each year (Dugdale *et al.*, 2007). Reproductive wastage occurs at all stages of the breeding cycle; 22% of sows failed to develop blastocysts and only 44% of adult sows implanted their blastocysts and proceeded to the end of pregnancy (Cresswell *et al.*, 1992). Body condition influences all stages of reproduction including development of blastocysts (Cresswell *et al.*, 1992) and implantation (Woodroffe, 1995). Poor sow health and higher bite wound scores also have a negative effect on blastocyst development (Cresswell *et al.*, 1992). The time of implantation also affects cub survival because birth early in the year provides cubs with the maximum period of growth prior to the summer when food availability is very low (Woodroffe, 1995). Lactation in the spring and body weight of cubs have both been shown to be influenced by the sow's body mass and fat deposits in the autumn and winter months (Delahay *et al.*, 2006a).

Cubs do not usually emerge from below ground until about eight weeks old, usually in April (Neal and Cheeseman, 1996). Cubs wean later compared with domestic

carnivores, typically from 12 weeks old (Neal and Cheeseman, 1996). Both parents and other members of the social group may be involved in care of the cubs (Neal and Cheeseman, 1996; Delahay *et al.*, 2008). Social integration of cubs into the natal group is gradual and cub-driven with young cubs exhibiting specific behaviour to mark themselves with the subcaudal gland secretion of adult group-members, shown to carry group-specific information (Fell *et al.*, 2006). Cub mortality can be as high as 50-65% during their first year (Cheeseman *et al.*, 1987; Cresswell *et al.*, 1992; Neal and Cheeseman, 1996; Rogers *et al.*, 1997b). Predation and starvation are the common causes of death in cubs (Neal and Cheeseman, 1996). It has been suggested that 35% of sows that produce cubs cease lactation early because of infanticide by dominant sows within the social group (Cresswell *et al.*, 1992).

1.3.5 Life expectancy

Dentition is commonly used as a method of assessment of age in badgers as described above (1.3.3). In animals under 18 months of age epiphyseal fusion has also been used as a means of ageing animals using radiography (Page, 1993) and at necropsy (Ahnlund, 1976; Cresswell *et al.*, 1992). The median ridge of the skull can also be used as an approximation of age during development from temporal ridges (up to ten months) and maturation into the sagittal crest (up to three years) (Neal and Cheeseman, 1996). Life expectancy of badgers in the wild rarely exceeds six years (Neal and Cheeseman, 1996; Delahay *et al.*, 2008) although anecdotal reports suggest badgers in captivity may live well into their teens (Neal and Cheeseman, 1996). There are high mortality rates in cubs as described above (1.3.4). Subsequently, annual mortality rates in populations of high density are around 30% for males and 24% for females (Neal and Cheeseman, 1996; Wilkinson *et al.*, 2000) resulting in an increasingly female population with age (Neal and Cheeseman, 1996; Rogers *et al.*, 1997b). Causes of mortality in adult badgers are discussed below (1.17).

1.4 Bite wounds (conspecific wounding, ‘territorial wounding’)

1.4.1 Occurrence of bite wounds

Fighting between badgers resulting in bite wounds has been described both at territorial boundaries and within sett areas (Kruuk, 1989; Cresswell *et al.*, 1992; Neal and Cheeseman, 1996). Such wounds are sometimes described as ‘territorial wounds’ (Mullineaux, 2003a). Bite wounds are associated with the postpartum breeding season being highest in male badgers in February to March, with a second less distinct peak in September, and most common in females in April (Cresswell *et al.*, 1992; Delahay *et al.*, 2006b). Veterinary admissions of badgers for bite wounds followed a similar pattern (Cousquer, 2002). Bite wounds were most common in March in a post-mortem study of badgers (Gallagher and Nelson, 1979), although these animals were collected following RTA or culling and the sample may consequently be bias. No seasonal effects were however, reported in another field study (Macdonald *et al.*, 2004b). Studies suggest that bite wounds occur more frequently in male than female animals (Macdonald *et al.*, 2004b; Delahay *et al.*, 2006b) and may be of greater severity in male animals (Cresswell *et al.*, 1992). Whilst testosterone concentrations show seasonal trends, no relationship between testosterone concentrations and bite wounds has been shown (Buesching *et al.*, 2009).

An increased incidence of bite wounds is reported in older badgers (Macdonald *et al.*, 2004b) with cubs less affected (Delahay *et al.*, 2006b). Studies vary in their findings of an association between bite wounds and body condition; badgers affected being in poor condition in one study (Delahay *et al.*, 2006b), whilst heavier animals were more likely to be affected in another (Macdonald *et al.*, 2004b). There are findings of an increased frequency of bite wounds associated with a higher population density (Macdonald *et al.*, 2004b) but this was not found in other studies where the frequency of bite wounds did not vary with either study site or density but did vary significantly between years (Delahay *et al.*, 2006b). In otters, an increase in the incidence of conspecific bite wounds has been associated with an increase in population density (Simpson, 2006).

Bite wounds are more frequent on the rump, head, neck and shoulder areas (Gallagher and Nelson, 1979; Lewis, 1997b; Cousquer, 2002). Bite wounds are found more frequently in the rump area in adult male badgers and on the head in cubs and female badgers (Delahay *et al.*, 2006b). Bite wounds become infected with mixed bacterial populations (Gallagher and Nelson, 1979), and cutaneous myiasis may be a complication during the summer months (Lewis, 1997b). Severe bite wounds are considered to be infrequent (Macdonald *et al.*, 2004b) and wounds generally heal quickly in the wild (Delahay *et al.*, 2006b), although individual animals may suffer potentially fatal effects such as the fatal pyothorax from a bite wound reported by Gallagher and Nelson (1979). Bites wounds may however be infected with *M. bovis* (Gallagher *et al.*, 1976; Gallagher and Nelson, 1979; Clifton-Hadley *et al.*, 1993; Gavier-Widen *et al.*, 2001; Jenkins *et al.*, 2008) and *M. bovis* infection in such instances has been described as severe and acute, with haematogenous spread to other organs (Gallagher and Nelson, 1979). Bite wounding was found to be the second most common cause of natural death in badgers after tuberculosis in a post-mortem study (Gallagher and Nelson, 1979). No significant correlation has however been shown between bite wounding and the incidence of tuberculosis (Clifton-Hadley *et al.*, 1993).

Veterinary treatment of bite wounds includes open wound management with topical cleaning followed by application of either hydrogels or semi-permeable spray dressings (Mullineaux, 2003a), and the attachment of hydrocolloid dressings over wounds using stay sutures (Cousquer, 2002). One report of surgical intervention to close a large wound found this method to be unsuccessful (Keeble, 1999). The use of broad-spectrum antibacterial drugs during the early stages of wound healing has been advocated (Cousquer, 2002; Mullineaux, 2003a).

1.4.2 Bacteriology of bite wounds

M. bovis has been cultured from bite wounds in several studies (Gallagher *et al.*, 1976; Gallagher and Nelson, 1979; Clifton-Hadley *et al.*, 1993; Delahay *et al.*, 2006b; Jenkins *et al.*, 2008). Classification of *M. bovis* strains from bite wound swabs may be carried out using molecular techniques, including spacer

oligonucleotide typing (spoligotyping) (Harris, 2006). There are few clinical bacteriological studies and no reported antibacterial sensitivity studies of isolated bacteria for cost reasons (Cousquer, 2002). Gallagher and Nelson (1979) reported mixed infections of *Staphylococcus pyogenes*, beta-haemolytic streptococci and coliforms in bite wounds. In the Eurasian otter where bite wounds may result from other otters, dogs and American mink (*Mustela vison*), *Streptococcus* species were predominant with mixed infections including *Staphylococcus* species, *Aeromonas hydrophila* and *Corynebacterium ulcerans* (Simpson, 2006).

1.5 Sedation and anaesthesia of badgers

The use of ketamine hydrochloride for anaesthesia has been described in a range of wild carnivores (Ramsden *et al.*, 1976). Ketamine was described as the sole anaesthetic agent permitting clinical examination and sampling of badgers (Hunt, 1976; Mackintosh *et al.*, 1976) and was subsequently used in field research work (Little *et al.*, 1982b; Cheeseman *et al.*, 1985; Cheeseman *et al.*, 1988). Ketamine allows safe handling, provides good recovery and appears to cause little distress (Hunt, 1976; Mackintosh *et al.*, 1976; Little *et al.*, 1982b). Other injectable anaesthetic agents considered during the 1980s were etorphine and halothane. Etorphine hydrochloride, reversed with diprenorphine, had serious human safety concerns and also resulted in the death of several badgers (Mackintosh *et al.*, 1976). Although considered a safe anaesthetic at that time, practicalities with halothane administration made it unsuitable for field use (Mackintosh *et al.*, 1976). Ketamine combined with acepromazine caused extended periods of sedation (Mackintosh *et al.*, 1976).

When used as the sole anaesthetic agent ketamine results in dissociative anaesthesia with poor muscle relaxation, involuntary movements and excitement in some species upon recovery (Kästner, 2007). Combinations of ketamine with other sedative or tranquillizer agents result in improved muscle relaxation and prolonged anaesthesia times; such drugs are usually benzodiazepines (e.g. diazepam, midazolam) or alpha-2 agonists (e.g. xylazine, medetomidine) (Kästner, 2007). The use of ketamine with benzodiazepines has been described in otters (Spelman, 1999) producing good short-

term anaesthesia. When ketamine was used with midazolam in badgers the depth of anaesthesia was not considered adequate for routine field procedures (Thornton *et al.*, 2005).

Medetomidine is a commercially available alpha-2 agonist commonly used in small animal veterinary practice. The use of medetomidine in combination with ketamine prevents the central nervous system excitement produced using ketamine alone, and produces deep sedation or general anaesthesia suitable for short duration surgical procedures (Murrell, 2007). In common with other alpha-2 agonists, medetomidine alone may result in respiratory and cardiovascular depression (Murrell, 2007) making this drug unsuitable for prolonged field anaesthesia. Combination of medetomidine with ketamine reduces some of these effects, as does reversal of the drug with an alpha-2 antagonist such as atipamazole (Murrell, 2007). The addition of an opioid, such as butorphanol, to the combination allows the dose rate of the other drugs to be reduced (Murrell, 2007). Medetomidine-ketamine and medetomidine-ketamine-butorphanol combinations are commonly used in domestic small animals, especially cats (Kästner, 2007). Ketamine in combination with medetomidine, then reversed with atipamazole, has been successfully used in several wildlife species (Roeken, 1990) including otters (Spelman *et al.*, 1994; Fernandez-Moran *et al.*, 2001). In the badger the combination of ketamine and medetomidine was initially considered to have few advantages over ketamine alone (Thornton *et al.*, 2005). Several authors considered the use of medetomidine in combination with ketamine and butorphanol in badgers for field work (de Leeuw *et al.*, 2004; McLaren *et al.*, 2005b) concluding that this combination (in various suggested doses) provided better quality anaesthesia than ketamine alone. The only notable concern was the sudden unexpected recovery from anaesthesia associated with a presumably drug-associated increase in rectal temperature (McLaren *et al.*, 2005a).

Other drug combinations have also been considered. Davison *et al.* (2007) compared a combination of romifidine, ketamine and butorphanol to one of medetomidine, ketamine and butorphanol, with the combination of medetomidine and ketamine alone; clinical parameters (heart, respiratory and body temperature, oxygen saturation) were not significantly different between the combinations, but the

recovery time was quicker using the romifidine combination and there was no need for reversal with atipamazole. The use of medetomidine in combination with fentanyl and fluanisole in the badger has also been described but recovery times varied from 11-50 minutes (Wolfensohn, 1992). The prolongation of ketamine-medetomidine anaesthesia with gaseous agents (isoflurane) has also been described for field anaesthesia in wild mammals (Mathews *et al.*, 2002) in badgers and mustelids such as the marten (Desmarchelier *et al.*, 2007). The field use of isoflurane in air is more easily applied to smaller mammals than badgers (Lewis, 2004; Drewe, *et al.*, 2009a).

Most clinical badger work is conducted using the combination of medetomidine-ketamine (Mullineaux, 2003a) and medetomidine-ketamine-butorphanol (Cousquer, 2005) combinations with reversal using atipamazole (Mullineaux, 2003a; Cousquer, 2005). Within the veterinary surgery gaseous anaesthetics such as isoflurane and sevoflurane, and intravenous agents such as thiopental and propofol may be used with greater ease than in the field (Best and Mullineaux, 2003) and a range these products and combinations of drugs have been described for use in badgers (Lewis, 1997c; Mullineaux, 2003a).

1.6 Biochemical and haematological parameters of badgers

Normal biochemical and haematological parameters used in clinical veterinary medicine have usually been obtained from research populations of badgers (Mullineaux, 2003a), although several other studies report from captive (Mahmood *et al.*, 1988) and free-living badger populations (Mahmood *et al.*, 1988; Woodroffe and Macdonald, 1995; Chambers *et al.*, 2000; Domingo-Roura *et al.*, 2001; Winnacker *et al.*, 2008). The largest study comprises badgers at the Woodchester Park field research area (Winnacker *et al.*, 2008), but has received criticism for originating from a bTB infected area (Denny, 2008), however this endemic disease situation may be typical for many wild badgers populations (Delahay, 2008).

1.6.1 Age and gender effects upon blood parameters

Lower haematocrit concentrations found in cubs compared to adults (Mahmood *et al.*, 1988; Winnacker *et al.*, 2008) were considered normal juvenile physiology

(Winnacker *et al.*, 2008). Lower serum albumin and globulin and higher alkaline phosphatase and calcium concentrations in cubs were also considered normal juvenile physiology (Domingo-Roura *et al.*, 2001; Winnacker *et al.*, 2008). Lower creatinine but higher triglycerides concentrations were present in cubs compared with adult badgers (Winnacker *et al.*, 2008) and contrary to an earlier study (Domingo-Roura *et al.*, 2001). Higher triglyceride concentrations in males were considered to be a dietary or hormonal effect (Winnacker *et al.*, 2008).

1.6.2 Dietary and seasonal effects upon blood parameters

High and variable urea concentrations were considered to be associated with a diet of earthworms (Winnacker *et al.*, 2008). Significant seasonal and body condition effects were found to occur on albumin/globulin and urea/creatinine ratios (Domingo-Roura *et al.*, 2001). Hypercholesterolaemia has also been reported in obese badgers (Domingo-Roura *et al.*, 2001).

1.6.3 Biochemistry and haematology in the course of tuberculosis

Increases in copper and gamma-glutamyl transferase (GGT) concentrations and red blood cells (RBCs) were present in badgers with tuberculosis (Mahmood *et al.*, 1988; Chambers *et al.*, 2000). Creatinine concentrations were significantly elevated in tuberculous badgers (Chambers *et al.*, 2000), possibly due to bacteraemic spread and renal disease. Calcium and bilirubin concentrations were also described as being lower in tuberculous badgers (Chambers *et al.*, 2000). Initial increased haematocrit values and leucocytosis were followed by reduced haematocrit values and leucopaenia as bTB progressed (Mahmood *et al.*, 1988). There was a relative monocytosis and neutrophilia but lymphopaenia late in the disease process (Mahmood *et al.*, 1988).

In humans, biochemical and haematological values have neither consistent pattern nor diagnostic significance in tuberculosis (Gordon and Mwandumba, 2008; Ormerod, 2008). Hypoalbuminaemia, hypoproteinaemia, normocytic anaemia and lymphopaenia may be associated with the chronic disease process (Lombard and Mansvelt, 1993; Hussain *et al.*, 2004), however many human TB cases and their associated clinical findings are complicated by concurrent human immunodeficiency

virus (HIV) infections (Enarson, 2006, Ritacco *et al.*, 2006; Thoen *et al.*, 2006). In domestic cats biochemistry and haematology values are not diagnostic and vary with the severity of TB (Gunn-Moore and Shaw, 1997).

1.6.4 Physical stress associated effects upon blood parameters

Transportation stress in badgers caused an increase in activated neutrophils (Montes *et al.*, 2004). Leucopaenia was recorded in recently-trapped wild badgers compared to those animals that had been captive for some time (Mahmood *et al.*, 1988). Exertional myopathy with elevation of creatine kinase concentrations has been recorded in badgers caught in leghold traps and snares (Williams and Thorne, 1996).

1.7 Diseases of badgers: General surveys

Wildlife health monitoring in the United Kingdom has long been considered poor compared to other developed countries (Sainsbury *et al.*, 2001). The benefits of monitoring include the control of infectious diseases (Delahay *et al.*, 2001) including tuberculosis (1.12). Limited surveillance work is carried out by the VLA (Duff, 2003; Duff *et al.*, 2010). Despite this awareness and extensive research involving badgers, there is limited information on clinical disease in the species with the exception of tuberculosis. Several literature reviews include badger diseases and parasites; Hancox (1980) reviewed the parasites and diseases of the Eurasian badger covering British and European records, Sleeman and Kelly (1997) reviewed the parasites and diseases found in badgers in Ireland, and Neal and Cheeseman (1996) described diseases and parasites that are regarded as causes of death in badgers. Many of the original studies referred to are included in the review below. Probably the most comprehensive work describing diseases of badgers was published more than 30 years ago (Gallagher and Nelson, 1979) and reported that road traffic accidents, tuberculosis and the consequences of bite wounds were the most common conditions.

1.8 Ectoparasite infections

1.8.1 Lice and fleas

The louse *Trichodectes melis* and flea *Paraceras melis melis* are the main badger ectoparasites (Hancox, 1980) with especially high numbers occurring in debilitated individual badgers (Gallagher and Nelson, 1979). *Paraceras melis melis* may also occur on foxes, dogs and fallow deer (Sleeman and Kelly, 1997). Other flea species *Pulex irritans* (human flea) and *Chaetopsylla trichosa* have also been described in badgers (Hancox, 1980; Sleeman and Kelly, 1997).

Flea movement on badgers is influenced by grooming behaviour (Stewart and Macdonald, 2003) and there is evidence of movement between sett chambers to avoid parasites (Butler and Roper, 1996). Fleas have been implicated in the transmission of *Trypanosoma pestanai* in badgers (Macdonald *et al.*, 1999).

1.8.2 Ticks

Several tick species have been reported on badgers including *Ixodes canisuga*, *Ixodes hexagonus*, and occasionally *Ixodes ricinus* (Hancox, 1980). Ticks have been implicated as vectors of *Babesia missirolii* (Peirce and Neal, 1974a; Gallagher and Nelson, 1979; Macdonald *et al.*, 1999) and louping-ill virus (Yuill and Seymour, 2001).

1.8.3 Mites

Cheyletiella parasitovorax infestation has been reported in badgers, especially cubs during the summer months (Newman *et al.*, 2004). Mange caused by *Sarcoptes scabiei* (Neal, 1997) has been reported in badgers in mainland Europe (Bornstein *et al.*, 2001). *Trombicula autumnalis* has also been reported in badgers (Hancox, 1980).

1.8.4 Fly larvae

Cutaneous myiasis (*Lucilia sericata*) has been reported in badgers (Sleeman and Kelly, 1997) and associated with bite wounds (Lewis, 1997b; Cousquer, 2002; Mullineaux, 2003a).

1.9 Endoparasite infections

Parasites of all three helminth groups affect the digestive and respiratory tracts of badgers. In Britain *Fasciola hepatica*, *Mesocestoides* sp. cf. *angustatus*, *Aelurostrongylus* sp. cf. *falciformis*, *Capillaria mustelarum* and *Molineus patens* have been reported (Hancox, 1980). A post-mortem study of badgers in Cornwall (Jones *et al.*, 1980) reported large numbers of *Capillaria erinacei* in the stomach of badgers, *Uncinaria stenocephala* and *Molineus patens* in the intestines and *Aelurostrongylus falciformis* a less common finding in the lung. *Strongyloides* spp., *Mesocestoides lineatus*, *Dilepis undula* and *Iyogonimus lorum* were found only as single specimens in the intestines probably as a result of accidental infestation. Conversely, *Aelurostrongylus falciformis* occurred at high prevalence levels in Cornwall and parts of Devon in a more recent survey (Gallagher *et al.*, 1998).

Lungworm, assumed to be *A. falciformis*, may result in verminous granulomata in the lungs and may be confused with tuberculous lesions (Gallagher *et al.*, 1998). *Aelurostrongylus* sp. larvae have been identified in bronchoalveolar lavage fluid from captive badgers (McCarthy *et al.*, 2009).

While Di Cerbo *et al.* (2008) considered *Trichinella* sp. and *Echinococcus multilocularis*, in badgers, red foxes (*Vulpes vulpes*), mustelids, and stone martens (*Martes foina*) as zoonotic risks in Italy, no such parasites were found in UK badgers.

1.10 Viral infections

1.10.1 Canine Distemper Virus

Canine Distemper Virus (CDV) has been described in badgers in mainland Europe; in Austria (Kölbl *et al.* 1990; Burtscher and Url, 2007), Germany (van Moll *et al.*, 1995) and Denmark (Hammer *et al.*, 2004). Respiratory disease (Hammer *et al.*, 2004; Burtscher and Url, 2007), and central nervous system (CNS) clinical signs and pathological lesions have been described (Kölbl *et al.*, 1990; Hammer *et al.*, 2004; Burtscher and Url, 2007), but not hyperkeratosis of pads (Hammer *et al.*, 2004). The CNS signs may be confused with rabies in countries where that disease is endemic

(Kölbl *et al.*, 1990). A serological study in the south and south west of England found no evidence of CDV in badgers (Delahay and Frölich, 2000).

1.10.2 Rabies

Badgers are not considered primary hosts for the rabies virus (Hancox, 1980) and only play a secondary role in the spread of disease throughout Europe (Wandeler *et al.*, 1974). In the event of a rabies outbreak badger populations are severely affected (Schwierz and Wachendörfer, 1981). The main vectors of rabies in Europe are the red fox, *Vulpes vulpes*, and an increasing number of racoon dogs, *Nyctereutes procyonoides* (Holmala and Kauhala, 2006). Contact between these species and badgers may increase the likelihood of badgers becoming vectors for rabies (Kauhala and Holmala, 2006). In the UK there may be interactions between foxes and badgers (Macdonald *et al.*, 2004a) allowing the spread of rabies if introduced. Should rabies ever become established within the UK badger population the spread of rabies from badger to badger would be a major concern, particularly in areas of high population density (Smith, 2002; Smith and Wilkinson, 2002).

1.10.3 Other viral infections

Serological evidence of mustelid herpes virus-1 (MusHV-1) has been found in badgers in the British Isles (King *et al.*, 2004) but with no clinical significance.

Although mustelids are susceptible to the feline parvovirus subgroup (including canine parvovirus), the susceptibility to disease is low with the exception of mink viral enteritis in farmed mink (Barker and Parish, 2001). Myocarditis lesions consistent with canine parvovirus (CPV) have been reported in badgers, but without serological evidence of disease (Burtscher and Url, 2007). Clinical signs and histopathological changes consistent with CPV infection have been described in cubs in rehabilitation facilities but virus isolation and serological confirmation of the disease could not be established (Mullineaux, 2003a).

1.11 Bacterial infections (other than *M. bovis*)

1.11.1 Leptospirosis

Three strains of leptospires belonging to three serogroups were isolated from badgers in the south west of England; *Leptospira australis*, *L. javanic* and *L. hebdomadis* (Salt and Little, 1987) where infection arose from eating infected rodents. Serological evidence of these serogroups has been reported elsewhere in Europe (Hancox, 1980). A member of the *sejroe* serogroup, *L. interrogans* serovar *saxkoebing* was isolated from badgers in another study (Little *et al.*, 1987). A study in Northern Ireland looking for *L. hardjo* as a source of infection for cattle failed to find evidence of infection in the local badger population (Ellis *et al.*, 1981). No clinical significance has been attached to leptospire infections in badgers (Gallagher and Nelson, 1979) and is in agreement with a paucity of reports of leptospirosis in free-ranging mammalian species (Leighton and Kuiken, 2001).

1.11.2 Salmonellosis

Salmonellae were isolated in 9% of badger carcasses and 8% of faecal samples (Wray *et al.*, 1977). Ten different serotypes were isolated with *Salmonella enterica* serovar *Agama* present in 71% of carcass samples and 52% of faecal samples (Wray *et al.*, 1977). *Salmonella* *Dublin*, the commonest serotype in cattle, was also isolated (Wray *et al.*, 1977). In a study in Cornwall 26 serotypes and one non-motile strain of salmonellae were found in badgers (Euden, 1990). In a more recent study 72% of badger social groups were found to excrete; *Salmonella enterica* serovar *Ried*, *S. enterica* serovar *Binza*, *S. enterica* serovar *Agama* and *S. enterica* serovar *Lomita* (Wilson *et al.*, 2003). Badgers excreting *S. enterica* serovar *Agama* were spatially clustered (Wilson *et al.*, 2003). No clinical significance has been attached to these Salmonellae infections in badgers (Gallagher and Nelson, 1979). *S. ajiobo*, *S. nagoya* and *S. berta* have additionally been cultured from badger cubs suffering from enteric disease during rehabilitation, these animals were also found to harbour a *Giardia* species, the clinical significance of these isolates remains unknown (VLA, 2009). *S. durham* and *S. stourbridge* have also recently been isolated from captive badger cubs with concurrent coccidiosis (A. Barlow *pers. comm.*); the clinical significance of the salmonellae in these cases has been questioned (E. Mullineaux, unpublished data).

1.11.3 Other bacterial diseases

Badgers are considered to be susceptible to anthrax (Hancox, 1980; Neal and Cheeseman, 1996; Gates *et al.*, 2001) but there are no reports of incidence or clinical findings. Badgers have been used as serological sentinel species for monitoring of zoonotic *Yersinia pestis* in North America (Gasper and Watson, 2001). The response of badgers to *Brucella abortus* infection has also been considered (Corbel *et al.*, 1983) but there is no reported clinical disease following natural exposure. Badgers have been found to harbour *Mycobacterium avium subspecies paratuberculosis* (Beard *et al.*, 2001) but no clinical significance in badgers has been attached to such isolation. *Borrelia burgdorferi sensu lato* has been isolated from a badger skin in Switzerland (Gern and Sell, 2009) but there are not reports of clinical Lyme disease in badgers.

1.12 Tuberculosis (*M. bovis* infection, bTB)

Mycobacterium bovis (bTB) infection in mammals, and especially badgers, is the subject of much research because of the potential zoonotic risks and the economic importance in trade of livestock, milk and meat products internationally, and to a lesser extent the impact on endangered species. However, much of the scientific literature is not directly relevant to badger rehabilitation and release and only salient information is reviewed below.

The implication of badgers in the spread of *M. bovis* infections to cattle however, significantly impacts upon the way in which badger rehabilitation and release is undertaken and perceived by the public, in particular the farming community. One result of this potential risk has been the necessity for formal guidelines for badger rehabilitation with specific consideration of *M. bovis* infection (Mullineaux, 2003b; SWWR *et al.*, 2003). Within the veterinary profession many members question and disregard scientific findings on bTB. It is therefore essential that this thesis fully investigates the role of wildlife hosts in the epidemiology of bTB, reviews significant statutory policies and political influences, and can offer impartial and evidence-based advice to rehabilitators and veterinary surgeons.

1.12.1 *M. bovis* infections: Introduction

Mycobacterium is a genus of non-sporing, non-motile Gram-positive bacteria most of which are saprophytic and non-pathogenic (Clifton-Hadley *et al.*, 2001). Members of the *Mycobacterium tuberculosis* complex are obligate pathogens and include *M. tuberculosis*, *M. africanum*, *M. canettii*, *M. bovis* and *M. microti* (Thoen and Barletta, 2006; Grange, 2008). *M. bovis* has the broadest host range of the *M. tuberculosis* complex (Sales *et al.*, 2001) and is one of three species (also *M. tuberculosis* and *M. africanum*) causing disease in man (Clifton-Hadley *et al.*, 2001; Grange, 2008) although all members of the complex are potentially secondary human pathogens (Thoen and Barletta, 2006; Grange, 2008). *M. tuberculosis* is considered primarily a human disease whilst *M. bovis* is considered to be a cattle disease with zoonotic potential (Clifton-Hadley *et al.*, 2001; Grange, 2008). The history of *M. bovis* as a zoonosis and the work of Koch and McFadyean have been well documented (Johnston, 2006). The geographical range of *M. bovis* parallels distribution of livestock in the world, although there is limited information available on infection levels in livestock in many developing countries (Kaneene and Pfeiffer, 2006). The disease has significant economic effects on communities as a result of effects in cattle, as well as economic effects on public health, wildlife, international trade and tourism (Zinsstag *et al.*, 2006). Control measures in developing countries are often poor or non-existent and the disease is enzootic (Enarson, 2006). There is little information on the true involvement of *M. bovis* in the current global tuberculosis epidemic in humans as many infections go untyped (Enarson, 2006), although in developed countries its significance is generally low (Pfeiffer, 2008).

1.12.2 *M. bovis* infections in badgers

1.12.2.1 Route of transmission

As is the case in mycobacterial infections in man (Gordon and Mwandumba, 2008), aerosol infection of the respiratory tract is the main route for spread of *M. bovis* between badgers (Gallagher *et al.*, 1976; Little *et al.*, 1982b; Clifton Hadley *et al.* 1993, Nolan and Wilesmith, 1994; Gallagher *et al.*, 1998; Delahay *et al.*, 2000; Jenkins *et al.*, 2008). Infection has been established experimentally by endobronchial inoculation in badgers (Corner *et al.*, 2007; Corner *et al.*, 2008c). Aerosol infection

also occurs in other species including the brushtail possum (*Trichosurus vulpecula*) (Cooke *et al.*, 1995; Jackson *et al.*, 1995a; Jackson *et al.*, 1995b) and meerkat (*Suricata suricatta*) (Drewe *et al.*, 2009b; Drewe, 2010).

Excretion of bacilli occurs in saliva, urine, faeces and pus from wounds and lymph node abscesses although excretion appears to be intermittent (Clifton-Hadley *et al.*, 1993). Most natural *M. bovis* infection occurs within the sett (Clifton-Hadley *et al.*, 2001) but areas such as latrines also act as foci of infection (Delahay *et al.*, 2007b). Bite wounds during social disputes (1.4) are another possible method of horizontal infection via contaminated saliva (Gallagher *et al.*, 1976; Gallagher and Nelson, 1979; Clifton-Hadley *et al.* 1993; Delahay *et al.*, 2006b; Jenkins *et al.*, 2008). Horizontal transfer of infection from mother to cubs is considered profoundly important in maintaining infection within social groups (Cheeseman *et al.*, 1989; Delahay *et al.*, 2000). In meerkats grooming behaviour and aggressive interactions are the main routes of social transmission (Drewe, 2010).

1.12.2.2 Social and group size effects

There is little movement of badgers between social groups within stable badger populations (Cheeseman *et al.*, 1988; Woodroffe *et al.*, 1995) and the risk of disease transfer between groups, including *M. bovis* infection, is consequently low (Cheeseman *et al.*, 1988; Delahay *et al.*, 2000). Ranging behaviour however, increases as badger density declines (Woodroffe *et al.*, 1995) and the incidence of *M. bovis* infection increases as social group sizes decreases, possibly as a result of increased movement between social groups (Vicente *et al.*, 2007; Woodroffe *et al.*, 2009).

Badger culling increases both the ranging of badgers within social groups and the prevalence of *M. bovis* infection (Pope *et al.*, 2007) and this has an impact on culling as a method of controlling bTB infections in cattle (1.12.7.3). Additionally, ranging behaviour increases with disease prevalence within a social group where tuberculous badgers have larger ranges than uninfected animals (Cheeseman and Mallinson, 1981; Garnett *et al.*, 2005). Such increased ranging activity increases with disease progression but it is unclear whether this is a direct effect on behaviour or a need for

increased feed resources (Garnett *et al.*, 2005). Sick badgers may also more commonly enter farm buildings in search of food (Cheeseman and Mallinson, 1981).

1.12.2.3 Clinical effects of the disease

RTAs are considered to be the major cause of badger mortality even in areas with endemic tuberculosis (Cheeseman *et al.*, 1988) however tuberculosis is still the predominant cause of natural deaths in all studies (Muirhead *et al.*, 1974; Gallagher and Nelson, 1979; Cheeseman *et al.*, 1988).

Adult badgers infected with *M. bovis* may live and breed normally for many years despite infection (Clifton-Hadley *et al.*, 1995b). Tuberculosis infection does not significantly affect the mortality rate of badgers when they are not excreting *M. bovis*, but mortality rates are significantly linked to bacterial excretion (Wilkinson *et al.*, 2000). Higher infection rates have been found in male badgers compared to females (Gallagher *et al.*, 1976; Gallagher and Nelson, 1979; Cheeseman *et al.*, 1988). Clinical signs of tuberculosis are typically weight loss leading to emaciation (Clifton-Hadley, 1993; de Lisle *et al.*, 2002), although behavioural changes can also occur (Garnett *et al.*, 2005).

In other species clinical signs are also non-specific; fever, cough and weight loss are the most common presenting signs in man, usually associated with pulmonary TB (NHS, 2006; Gordon and Mwandumba, 2008; Schluger, 2008). Clinical signs associated with localisation of infection outside the respiratory tract may reflect inflammatory changes in a variety of other organs (NHS, 2006; Kumar *et al.*, 2007; Ormerod, 2008). Similar findings have been observed in domestic animal species such as cats (Gunn-Moore *et al.*, 1996; Gunn-Moore and Shaw, 1997). The significance of such findings to badgers is fully discussed in Chapter 6.

Biochemical (Chambers *et al.*, 2000) and haematological parameters (Mahmood *et al.*, 1988; Chambers *et al.*, 2000) associated with tuberculosis in badgers have been described (1.6.3) but vary during the disease progression (Mahmood *et al.*, 1988). Although abnormal organ-specific biochemical parameters may be linked to tuberculous lesions, such biochemical findings may also be influenced by other disease conditions (Chambers *et al.*, 2000).

1.12.2.4 Necropsy

Poor body condition extending to emaciation are the main findings at post-mortem examination of tuberculous badgers (Clifton-Hadley *et al.*, 1993). Visible lesions are commonly found at the primary sites of infection in the lungs and/or bronchio-mediastinal lymph nodes (Muirhead *et al.*, 1974; Gallagher *et al.*, 1976; Gallagher and Nelson, 1979; Clifton-Hadley *et al.*, 1993; Gallagher *et al.*, 1998; Gavier-Widen *et al.*, 2001; Jackson *et al.*, 2008). Lesions vary from miliary foci to caseous abscesses (Gallagher *et al.*, 1976; Clifton-Hadley *et al.*, 1993; Gavier-Widen *et al.*, 2001) but the degree of caseation and calcification is less than that seen in cattle (Gallagher *et al.*, 1976). Lung lesions may be confused with adiaspiromycosis (Gallagher *et al.*, 1998; Borman *et al.*, 2009). The liver (Gallagher *et al.*, 1976; Clifton-Hadley *et al.*, 1993; Gavier-Widen *et al.*, 2001) spleen (Clifton-Hadley *et al.*, 1993; Gavier-Widen *et al.*, 2001) and kidney (Gallagher *et al.*, 1976; Gallagher *et al.*, 1998; Clifton-Hadley *et al.*, 1993; Gavier-Widen *et al.*, 2001; Jenkins *et al.*, 2008) may show evidence of infection arising from haematogenous spread from lungs or another primary lesion such as a bite wound (Gallagher *et al.*, 1976; Gallagher and Nelson, 1979; Pritchard *et al.*, 1987; Gallagher *et al.*, 1998; Clifton-Hadley *et al.*, 1993; Jenkins *et al.*, 2008). Very small foci have been found in the lungs of badgers (Gallagher *et al.*, 1998), consistent with Gohn foci in man (Kumar *et al.*, 2007; Gordon and Mwandumba, 2008) suggesting containment or resolution of the primary disease (Gallagher *et al.*, 1998; Gordon and Mwandumba, 2008). The majority of infected badgers have no visible lesions at post-mortem examination (Gallagher *et al.*, 1998; Clifton-Hadley *et al.*, 1993; Corner, 2006; Jenkins *et al.*, 2008; Murphy *et al.*, 2010) therefore standard post-mortem examinations will underestimate infection rates in badgers and more detailed necropsy and culture techniques must be employed to identify infected animals (Corner, 2006; Crawshaw *et al.*, 2008; Jenkins *et al.*, 2008; Murphy *et al.*, 2010). Badgers without visible lesions may represent early containment of disease or latent infection that may become active at a later date or less likely completely resolve (Gallagher *et al.*, 1998).

1.12.2.5 Zoonotic risks

The non-specific clinical signs associated with *M. bovis* infection in badgers together with behavioural changes in tuberculous animals which increases their likely contact with man through visits to farms and buildings, has implications for the rehabilitation and release of badgers both in terms of effective triage and zoonotic risks to staff. These concerns are reviewed in 1.12.4 and discussed in Chapter 6.

1.12.3 Clinical diagnosis of *M. bovis* infections in badgers

The diagnosis of *M. bovis* infection in live animals relies upon either the detection of primarily cell mediated immune responses or the culture of the causal organism from body secretions (Cousins and Florisson, 2005). Cell mediated responses may represent existing or historical (latent or resolved) infections, whilst organism culture confirms active infection.

1.12.3.1 Intradermal skin tests

In cattle a single or comparative intradermal tuberculin skin test (TST) using bovine +/- avian purified protein derivatives (PPD) from mycobacterial cultures to generate a delayed type hypersensitivity (type IV) reaction is used worldwide (Monaghan *et al.*, 1994; Thoen and Ebel, 2006). Although the test has variable and often low sensitivity (Monaghan *et al.*, 1994), it has been used successfully in disease control campaigns in cattle through aggressive interpretation at a herd level (Pfeiffer, 2008). In man, the tuberculin skin test (TST), usually as a Mantoux test (or alternatively a Heaf test or Tine test), is used in a similar way to diagnose latent TB cases usually in an investigation of in-contacts following an active TB case or as a population surveillance tool (NHS, 2006; Cook *et al.*, 2008). Intradermal testing has been shown to be ineffective in diagnosing *M. bovis* infections in badgers (Zuckerman, 1980; Little *et al.*, 1982b; Mahmood *et al.*, 1987a; Mahmood *et al.*, 1987b).

1.12.3.2 Clinical sampling

Culture and microscopical examination of body secretions (saliva, lymph node aspirates, urine, faeces) for acid-fast bacteria (AFB) using Ziehl-Neelsen or auramine staining is useful in the diagnosis of TB and assessment of active infection. Sputum-based tests remain crucial to the diagnosis of tuberculosis in man (NHS, 2006;

Schluger, 2008) where techniques such as sputum induction using nebulised hypertonic saline, gastric lavage, bronchoscopy and nucleic acid amplification assays may be used to aid diagnosis (Schluger, 2008). Cultures from badgers may be a useful method of detecting *M. bovis* infection during the latter stages of disease (Little *et al.*, 1982b) however intermittent shedding during the course of infection limits the sensitivity of such techniques in detecting all infected animals (Little *et al.*, 1982b; Clifton-Hadley *et al.*, 1993; Gallagher and Clifton-Hadley, 2000; Chambers *et al.*, 2002). In meerkats, culture of tracheal washes had high specificity but low sensitivity for diagnosis of *M. bovis*-infected individuals (Drewe *et al.*, 2009a). The practicalities of many of these test methods together with the 4-7 weeks taken for culture make such investigative procedures impractical for most live testing in badgers (Little *et al.*, 1982b; Crawshaw *et al.*, 2008).

1.12.3.3 Radiography

Chest radiography is the primary test in the UK in humans over 35 years old who have been vaccinated with Bacillus Calmette-Guérin (BCG) (NHS, 2006; Schluger, 2008). Cases of primary tuberculosis typically show paratracheal and hilar lymph node enlargement; pleural effusion may also occur (Gordon and Mwandumba, 2008). Post-primary cases have variable radiographic signs including lung infiltrates or consolidation, sometimes with cavitation in the cranial lung lobes, with or without mediastinal or hilar lymphadenopathy (Kumar *et al.*, 2007; Gordon and Mwandumba, 2008). Miliary tuberculosis resulting from the haematogenous dissemination of infection via the pulmonary vein to the lungs and other organs (liver and spleen) classically shows a radiographic pattern of diffuse calcified granulomas throughout the lung field (Kumar *et al.*, 2007; Gordon and Mwandumba, 2008).

Non-respiratory TB in man may also be illustrated with radiographic findings. Skeletal lesions in man are most commonly associated with the spine, followed by the hip and knee, but may occur at other bones sites. Gastrointestinal and renal TB may be illustrated using radiographic contrast techniques (Ormerod, 2008). Advanced imaging techniques such as magnetic resonance imaging (MRI) and computer tomography (CT) best illustrate CNS lesions and are increasingly used in

developed countries to image both primary and post-primary lesions in other body areas.

Radiographic findings associated with tuberculosis in cats have been reported in the abdominal viscera, long bones and lymph nodes (Gunn-Moore *et al.*, 1996; Gunn-Moore and Shaw, 1997). There are no reports of radiographic techniques for the diagnosis of tuberculosis in badgers, although these and other imaging techniques have been considered for research purposes (S. Lesellier, *pers. comm.*).

1.12.3.4 Post-mortem examination

Post-mortem examination of badgers combined with bacterial culture of tissue samples using selective media (Gallagher and Horwill, 1977) was considered the most sensitive method for detecting *M. bovis* infection in badgers (Pritchard *et al.*, 1986, Clifton-Hadley *et al.*, 1993). Such post-mortem testing is limited in contributing to our knowledge of bTB in free-living species such as badgers (de Lisle *et al.*, 2002) because it does not always differentiate between latent infection and active tuberculosis, and cannot be applied in live animals. Recently, the sensitivity of this standard testing procedure has been questioned because it may significantly underestimate *M. bovis* infection prevalence in badgers (Corner, 2006; Crawshaw *et al.*, 2008; Jenkins *et al.*, 2008; Murphy *et al.*, 2010) (1.12.2.4). In several studies in man however, viable mycobacteria have been recovered from up to 50% of apparently normal lung samples in patients that have died from diseases other than tuberculosis, especially in areas of high TB prevalence (Gordon and Mwandumba, 2008).

1.12.3.5 Serological tests

Serological tests for *M. bovis* have advantages for live testing of non-bovine species compared with culture techniques in terms of cost and speed of results (Cousins and Florisson, 2005). Antibody responses to mycobacteria vary during the course of the disease. In man specific antibodies are typically detectable following recent infection and progression of latent infection to active TB, but absent during the latent phase (Schwander and Ellner, 2008). Until 2009 the only *M. bovis* serological test available to badgers rehabilitators was the indirect 'Brock' enzyme linked immunoassay

(ELISA) (Goodger *et al.*, 1994a) which has low sensitivity (40.7%) but high specificity (94.3%) making it useful for testing groups of animals (Clifton-Hadley *et al.*, 1995a), but of limited use in individual animals for rehabilitation (SWWR *et al.*, 2003). Subsequent studies have shown the test sensitivity to range between 37% and 53%, and its specificity between 89% and 98% (Greenwald *et al.*, 2003; Sawyer *et al.*, 2007). The sensitivity of the test increases with advanced disease (Clifton-Hadley *et al.*, 1995a; Chambers *et al.*, 2008) and in those badgers shedding *M. bovis* (Chambers *et al.*, 2002). Multiple applications of the test increases sensitivity to 79.5% but reduces specificity to 83.1% after three tests (Forrester *et al.*, 2001). In rehabilitation situations three tests are performed at approximately equal intervals during the 4-6 months of the badger rearing process ('triple testing') in an attempt to ensure that badger cubs are free of *M. bovis* infection prior to release (SWWR *et al.*, 2003).

New serological assays have been developed to test for immune responses to multiple mycobacterial proteins (Lyashchenko *et al.*, 1998; Amadori *et al.*, 2002). These include multi-antigen print immunoassays (MAPIA) (Lyashchenko *et al.*, 2000) and the lateral-flow immunoassay (rapid test) (Greenwald *et al.*, 2003; Lyashchenko *et al.*, 2003). Where used in tuberculous meerkats the MAPIA test showed high sensitivity but low specificity whilst the rapid test showed high specificity but low sensitivity as had previously been shown in badgers (Chambers *et al.*, 2008). In meerkats, a combination of the tests in parallel was considered to produce levels of specificity and sensitivity high enough to allow informed decision making of exposure to bTB based upon live tests alone (Drewe *et al.*, 2009a).

A lateral-flow immunoassay (rapid test) is commercially available for use in badgers as the Brock Tb Stat-Pak® (Chembio Diagnostic Systems, Medford, NY) and has been shown to be 49% sensitive and 93% specific for detecting *M. bovis* (Chambers *et al.*, 2008). The sensitivity of the test increases from 66% to 78% in badger with more severe disease (Chambers *et al.*, 2008). The test has also been shown to be an additional aid to diagnosis of *M. bovis* in badgers post-mortem (Chambers *et al.*, 2010). Since the withdrawal of the Brock ELISA in 2009 the Stat-Pak® has been the only test available for use by rehabilitators.

1.12.3.6 Interferon-gamma testing

Immunodiagnostic tests in both man and animals measure interferon (IFN)- γ released by memory T-lymphocytes (usually from CD4+ TH1-cells) *in vitro* when re-exposed to specific mycobacterial antigens associated with the *M. tuberculosis* complex bacteria. IFN- γ tests therefore represent CD4+ T-cell immunity indicative of recent infection (e.g. recent in contact cases in man) or ongoing infection (active or latent), however the tests do not differentiate between active TB and latent disease. Factors negatively affecting cell-mediated immunity such as age, immunosuppression and advanced disease can reduce IFN- γ responses (Nyendak *et al.*, 2008).

Commercially available IFN- γ assays have been successfully used in cattle to detect cellular responses to *M. bovis* infection (Gormley *et al.*, 2006). A badger IFN- γ test has been developed (Dalley *et al.*, 1999; Dalley *et al.*, 2004; Sawyer *et al.*, 2007; Dalley *et al.*, 2008) and an enzyme linked immunoassay produced with sensitivity and specificity values of 81% and 94%, respectively (Dalley *et al.*, 2008). A recent evaluation of this test suggested a sensitivity of 57% in badger cubs and 85% in adults when a common cut off point was applied (Chambers *et al.*, 2009). A commercial badger IFN- γ test is not currently available and may be limited in its availability to rehabilitators as a result of the need to process samples within relatively short time periods (R. Delahay, *Pers. comm.*). Although overnight storage of samples from cattle did not significantly reduce the test sensitivity (Whelan *et al.*, 2004; Coad *et al.*, 2007) processing of samples in man is always completed within twelve hours (Nyendak *et al.*, 2008).

1.12.3.7 Combinations of tests

A combination of test methods; culture of clinical samples, Stat-Pak® and IFN- γ assay, has recently been applied to live badgers with suggested improvements in both sensitivity and specificity of testing for *M. bovis* infection compared with any single test (Drewe *et al.*, 2010).

1.12.3.8 Other biomarkers

All current tests for TB in man and animals including the IFN- γ tests, fail to differentiate between those patients infected with *M. tuberculosis* or *M. bovis* with latent disease, and those with active clinical disease. Biomarkers representing differential genetic expression between the two groups of patients have been identified (Jacobsen *et al.*, 2007) and provide the first steps towards tests allowing such useful clinical distinction.

1.12.4 *M. bovis* as a zoonosis

M. bovis has the broadest host range of the *M. tuberculosis* complex and causes disease in a wide range of species including man. There are strains of *M. bovis* with genotypic characteristics between *M. bovis* and *M. tuberculosis* including *M. africanum* strains (Sales *et al.*, 2001; Grange, 2008). Some spoligotypes of *M. bovis* infections in man are common between humans and cattle whilst some human spoligotypes have not been recorded in cattle (Gibson *et al.*, 2004).

The importance of *M. bovis* in human tuberculosis was debated for many years most notably between Kock and McFadyean in the 1900s (Johnston, 2006; LoBue, 2006). Subsequent work by the British Royal Commission and others showed a clear link between contaminated milk and disease in children or inhalation of droplets leading to the pulmonary form of the disease (LoBue, 2006; Pfeiffer, 2008). *M. bovis* is classed by the OIE as a Risk 3 (scale 1-4) pathogen for public health (Thoen *et al.*, 2006).

During the early 1900s *M. bovis* tuberculosis was a major cause of human disease, mostly as a result of extra-pulmonary infections through the ingestion of infected milk (Thoen *et al.*, 2006). The incidence of human *M. bovis* related tuberculosis in most of the developed world has plummeted with pasteurisation of milk and eradication of bovine tuberculosis (Thoen, *et al.*, 2006; Pfeiffer, 2008). In the developed world, *M. bovis* infection incidence ranges from less than 1% to 2.9% of human cases (Enarson, 2006; Thoen *et al.*, 2006), in most of Europe about 0.5% of reported cases are *M. bovis*-related (Pfeiffer, 2008).

Cow to human transmission still occurs via unpasteurised milk in USA-Mexico border areas, Latin American, Caribbean Islands and in many other developing countries (LoBue, 2006; Ritacco *et al.*, 2006). In some developed countries pasteurisation of milk has reduced oral infection with *M. bovis* but the airborne route remains frequent especially in the meat industry (Thoen *et al.*, 2006). People exposed in meat packing plants have pulmonary pathology through aerosol exposure (de Kantor and Ritacco, 2006; LoBue, 2006; Ritacco *et al.*, 2006). Confirmation of *M. bovis* in these situations may be poor due to the cost of testing and only smear testing is employed (Ritacco *et al.*, 2006). Recreational aerosol exposure to *M. bovis* infection is possible in those countries with a culture of hunting and dressing carcasses of tuberculosis susceptible species such as elk in Canada and white tailed deer in the USA (Enarson, 2006; LoBue, 2006).

In most developing countries the true incidence of *M. bovis* infection in cattle, *M. bovis* related disease in man, and the effectiveness of pasteurisation of milk remain unknown because many countries do not type TB infections (Thoen *et al.*, 2006). As is the case with *M. tuberculosis*, HIV infection significantly increases the incidence of *M. bovis*-related disease in man (Enarson, 2006, Ritacco *et al.*, 2006; Thoen *et al.*, 2006). HIV is the main cause of the rise in TB cases in man in developing (Harries and Zachariah, 2008) and industrialized (Pozniak, 2008) countries. Poor nutrition, social (smoking and drinking) and environmental factors (exposure to cooking smoke or industrial pollutants) are also important in the epidemiology of the disease (Gordon and Mwandumba, 2008). Human-to-human transmission of *M. bovis* infection becomes important where HIV related immunosuppression results in active pulmonary tuberculosis. Contaminated dairy products may contribute to extrapulmonary infections in populations with a high percentage of HIV-positive individuals (Ritacco *et al.*, 2006).

In the UK, human infection with *M. bovis* is largely controlled through pasteurisation of milk and culling cattle reacting to statutory tuberculin testing. Only 0.5-1.5% of confirmed human TB cases annually are attributable to *M. bovis* and of these cases most are as a result of reactivation of long-standing latent infections acquired before widespread adoption of milk pasteurisation, or as a result of *M. bovis* infections

contracted abroad (de la Rua-Domenech, 2006). Clusters of *M. bovis* infection in man show evidence of human-to-human transmission rather than zoonotic links or exposure to unpasteurised dairy products (Evans *et al.*, 2007). A study of human cases of *M. bovis* infection in the UK from 1997-2000 found 59% of these to have some contact with farm livestock, however in most instances the actual source of infection was not determined (Gibson *et al.*, 2004; Smith *et al.*, 2004). Veterinary occupational cases possibly arising from zoonotic infection are described (Shrikrishna, *et al.*, 2009; Twomey *et al.*, 2010) but the sources of such infections are poorly defined. *M. bovis* infections in man in the UK have not increased despite large increases in cattle herd infection rates (Jalavak *et al.*, 2007). Spoligotypes of *M. bovis* infections in man include isolates not yet recorded in cattle (Evans *et al.*, 2007), whilst transmission of *M. bovis* from infected humans to cattle has also been described (Fritsche *et al.*, 2004).

The clinical diagnosis of tuberculosis in man has been reviewed above and is further discussed in Chapter 6. Treatment of *M. bovis* infection in man is targeted at contagious patients with active TB and those who may become contagious through reactivation of latent TB. Treatment of human TB including *M. bovis* infections involves the use of combinations of drugs (Peloquin, 2008). Standard treatments for TB in the UK are six months of isoniazid and rifampicin plus two months of pyrazinamide and ethambutol (NHS, 2006). Chemotherapeutic agents are used in multiple drug resistant cases and non-respiratory active TB (NHS, 2006; Yew, 2008). In many instances direct observation of therapy (DOT) is an important part of ensuring drug compliance and minimising drug resistance (Squire, 2008).

The zoonotic risks of *M. bovis* infections must be addressed when treating badgers in veterinary practices and wildlife rehabilitation centers (Mullineaux, 2003a).

1.12.5 *M. bovis* in other animal species

M. bovis infections affect all domesticated bovids: cattle (*Bos taurus* and *Bos indicus*), water buffalo (*Bubalus bubalis*) and other hoof stock. The disease has particular economic significance in cattle (Bennett and Cooke, 2006; Zinsstag *et al.*, 2006) and farmed deer (Griffin and Macintosh, 2000; de Lisle *et al.*, 2001; Bolske *et*

al., 2006; Kaneene *et al.*, 2006; Partridge *et al.*, 2008). Wild boar (*Sus scrofa*) and feral pigs (*Sus scrofa domestica*) may also be affected (Corner, 2006; Dondo *et al.*, 2006; Moda, 2006; Reviriego Gordejo and Vermeersch, 2006).

Infection of free-ranging wildlife is considered to be a spill-over effect from domestic animal populations (Corner, 2006). Many animal species can become infected by consumption of infected fallen stock and infection levels in wildlife fall when carcasses are correctly removed (Corner, 2006). *M. bovis* infections have been reported in a variety of wildlife species including; cervids and other artiodactylae (Kaneene *et al.*, 2006; Kriek, 2006; O'Brien *et al.*, 2006), mongoose, including banded mongooses (*Mungos mungo*) (Alexander *et al.*, 2002) and meerkats (*Suricata suricatta*) (Alexander *et al.*, 2002; Drew *et al.*, 2009a; Drew *et al.*, 2009b; Drewe, 2010), and several species of non-human primates (Frost, 2006). *M. pinnipedii* is the predominant infection of the *M. tuberculosis* complex to affect fur seals and sea lions, although there is an anecdotal report of *M. bovis* in a seal (Cousins, 2006).

In the UK *M. bovis* infection has been identified in deer (*Cervus sp.*, *Capreolus sp.*, *Dama sp.*), red fox (*Vulpes vulpes*), mink (*Mustela vison*), feral ferret (*Mustela furo*), mole (*Talpa europaea*), brown rat (*Rattus norvegicus*) and feral cat (*Felis catus*) (Delahay *et al.*, 2001; Delahay *et al.*, 2002) and more recently; stoat (*Mustela erminea*), polecat (*Mustela putorius*), common shrew (*Sorex araneus*), yellow-necked mouse (*Apodemus flavicollis*), wood mouse (*Apodemus sylvaticus*), field vole (*Microtus agrestis*) and grey squirrel (*Sciurus carolinensis*) (Delahay *et al.*, 2007a).

Domestic pets may be infected with *M. bovis*. Cats are susceptible to a range of Mycobacteria including *M. bovis* (de Lisle *et al.*, 1990; Wilesmith and Clifton-Hadley, 1994; Gunn-Moore *et al.*, 1996; Gunn-Moore and Shaw, 1997; Monies *et al.*, 2000; Monies *et al.*, 2006). The life style of cats makes them most likely to encounter rodents infected with *M. microti*, although transmission of *M. bovis* from unpasteurised milk, cattle or badgers, is also possible and results in classical tuberculosis (Gunn-Moore and Shaw, 1997). An IFN- γ test has been adapted for feline tuberculosis diagnosis (Rhodes *et al.*, 2008). Tuberculosis in dogs was historically a common infection caused by both *M. tuberculosis* and *M. bovis* (Ellis

et al., 2006). Subsequent to falling disease incidence in man, reports of tuberculosis in dogs in developed countries are much less common (de Lisle, 1992; Pavlik *et al.*, 2002; Bauer *et al.*, 2004; Ellis *et al.*, 2006; Shrikrishna *et al.*, 2009; van de Burgt *et al.*, 2009). Most recently, a possible occupational link between a veterinary nurse and her dog in the UK has been reported (Shrikrishna *et al.*, 2009). Some authors have attempted to link canine infections to badgers (Shrikrishna *et al.*, 2009; van de Burgt *et al.*, 2009) but the epidemiology of such transmission remains uncertain. Tuberculosis in dogs in India remains high as a result of infection from multiple sources (Verma, 2006).

M. bovis tuberculosis has been a significant cause of morbidity and mortality in zoo collections where it carries a zoonotic risk. Tuberculosis, resulting from infections of either *M. bovis* or *M. tuberculosis*, most commonly occurs in ungulates, including elephants (usually Asian elephants *Eliphas maximus*) and rhinoceros (several species) and non-human primates. The signs of infection are usually chronic respiratory disease and/or weight loss. An increased awareness of the disease has restricted spread between individuals and between collections by screening and quarantine (West, 2006). Despite such controls outbreaks of tuberculosis are still reported in zoo collections (Schmidbauer *et al.*, 2007).

Strict isolation facilities must be available during hospitalisation of domestic and wild animals, and during rehabilitation, to prevent spread of *M. bovis* between species (Mullineaux, 2003b).

1.12.6 Significance of wildlife as a reservoir for *M. bovis* infections in domesticated livestock

The presence of *M. bovis* infection in a wildlife species does not necessarily create a reservoir of infection, or a significant risk for infection of domestic livestock (Corner, 2006). Infection in maintenance hosts persists and presents a reservoir of infection within the species whilst spill-over hosts do not persistently maintain infection within the population unless there is re-infection from another source (Morris and Pfeiffer, 1995; Corner, 2006). Both maintenance and spill-over hosts may act as disease vectors for livestock (Corner, 2006). Individual animal factors

(route of infection in wild animal, presence of lesions, route of excretion and dose and route of infection of domestic species), and population dynamics (number of susceptible and infectious animals and conditions for spread of infection), influence the transmission of bTB between animal populations and the definition of hosts as spill-over or maintenance (Corner, 2006). The definition of hosts as ‘spill-over’ or ‘maintenance’ may therefore vary according to these factors and their risk to livestock accordingly. Relative risks from wildlife reservoir infection have been calculated where *M. bovis* eradication remains problematic in domesticated livestock (Morris *et al.*, 1994; Corner, 2006).

1.12.6.1 Wildlife maintenance hosts of *M. bovis* infection

The most significant species considered in the transmission of *M. bovis* from wildlife to cattle in the UK and Ireland is the badger (*Meles meles*) (see 1.12.7).

The Australian brushtail possum (*Trichosurus vulpecula*) was introduced into New Zealand to create a fur trade during the 1840s and its numbers greatly increased (Clifton-Hadley *et al.*, 2001). *M. bovis* infection was first identified in possum in 1967, probably as a result of infection from cattle, and possums now represent a major maintenance host in the country and reservoir of infection for cattle and deer (Morris *et al.*, 1994; Morris and Pfeiffer, 1995; Clifton-Hadley *et al.*, 2001; Jackson, 2002; Kaneene and Pfeiffer, 2006). Possums are highly susceptible to *M. bovis* (Ramsey and Cowan, 2003; Corner, 2006) and infection spreads rapidly because bacteria are transmitted via various fomites and animals share dens (Morris *et al.*, 1994; Morris and Pfeiffer, 1995; Jackson *et al.*, 1995b; Ramsey and Cowan, 2003; Kaneene and Pfeiffer, 2006). The seasonal increase in *M. bovis* infection prevalence may be caused by possums gathering for mating and as a result of the stress of harsh winters (Kaneene and Pfeiffer, 2006). The inquisitive behaviour of cattle and deer towards debilitated possums may increase the risk of disease transmission (Morris *et al.*, 1994; Jackson *et al.*, 1995b; Clifton-Hadley *et al.*, 2001).

Culling of brushtail possum as a control measure for *M. bovis* infection in cattle and deer in New Zealand has been shown to reduce *M. bovis* prevalence in cattle (Corner, 2006) and ferrets (Caley and Hone, 2004). Fertility control has been

successfully employed to reduce *M. bovis* infection in possum populations (Ramsey *et al.*, 2006) and vaccination of possum has also been used successfully to control bTB (Corner *et al.*, 2001; Corner *et al.*, 2002a; Corner *et al.*, 2002b; Buddle *et al.*, 2006). The incidence of confirmed bTB in cattle is influenced by the proximity and size of local possum habitat despite intensification of possum control methods (Porphyre *et al.*, 2008) whilst the need to maintain possum control has considerable economic and welfare costs (Warburton and Nugent, 2009).

White-tailed deer (*Odocoileus virginianus*) are a primary reservoir and maintenance host for *M. bovis* infection in the Michigan area of the USA where the politics of hunting adversely affects the control of bTB (O'Brien *et al.*, 2006) facilitating the disease spread by intentionally feeding deer and permitting access to cattle resources (Corner, 2006; Kaneene and Pfeiffer, 2006; O'Brien *et al.*, 2006; Berentsen *et al.*, 2008). Problems associated with slaughter surveillance compliance also hinder eradication of bTB in the USA (Kaneene *et al.*, 2006).

M. bovis infection in wild boar (*Sus scrofa*) populations have been associated with failure to eradicate *M. bovis* in some Mediterranean countries (Reviriego Gordejo and Vermeersch, 2006) especially in the Piemonte (Moda, 2006) and Liguria (Dondo *et al.*, 2006) regions of Italy where they may act a maintenance hosts. Lobbying for recreational hunting has hindered compulsory eradication policies (Moda, 2006). Conversely, feral pigs (*Sus scrofa domestica*) in Australia and New Zealand are considered to be spill-over hosts for the disease and of limited epidemiological significance in *M. bovis* infection of domesticated species (Corner, 2006).

Feral asian water buffalo (*Bubalus bubalis*) in Australia have historically carried a high prevalence of *M. bovis* infection, however as a result of depopulation and differences in geographical range they no longer have contact with cattle so are not considered significant maintenance hosts (Corner, 2006; Radnuz, 2006).

1.12.6.2 Wildlife spill-over hosts of *M. bovis*

M. bovis infection has been described in feral ferrets (*Mustela furo*) in New Zealand (Lugton *et al.*, 1997a; Lugton *et al.*, 1997b; Clifton-Hadley *et al.*, 2001; Caley and Hone, 2004; Corner, 2006) where they are considered spill-over hosts as a result of

scavenging infected carcasses (Lugton, 1997b) including possum (Caley and Hone, 2004). Whilst ferrets have a high prevalence of *M. bovis*, they do not normally act as maintenance hosts because of their low population density (Corner, 2006) although in high population densities that may differ (Caley and Hone, 2004). Consequently, there is no scientific justification for culling ferrets in New Zealand and efforts concentrate upon reducing *M. bovis* infection in possum (Morris and Pfeiffer, 1995; Lugton *et al.*, 1997a; Lugton *et al.*, 1997b; Caley and Hone, 2004; Corner, 2006; Warburton and Nugent, 2009).

M. bovis spill-over infection of free-ranging cervids tends to occur sporadically and is caused by disease in other species, most notably cattle (Clifton-Hadley *et al.*, 2001). *M. bovis* may also infect the elk (*Cervus elaphus nelsoni*) population in the USA and spill-over into carnivorous species such as bear, racoon, coyote, fox and bobcat (O'Brien *et al.*, 2006).

The free-ranging wood-bison (*Bison bison athabasca*) (Nishi *et al.*, 2006) and wapiti elk (*Cervus elaphus manitobensis*) (Koller-Jones *et al.*, 2006; Nishi *et al.*, 2006) act as spill-over hosts of *M. bovis* infection into domestic cattle and bison in Canada (Nishi *et al.*, 2006). Common to many wildlife conservation projects, there are political, economic and social factors affecting the control of *M. bovis* in spill-over hosts in such wilderness areas (Nishi *et al.*, 2006).

M. bovis infection presents a problem in national parks and game ranches when transmission occurs from domestic cattle to free ranging buffalo (*Syncerus caffer*) (Kaneene and Pfeiffer, 2006; Michel *et al.*, 2006) with subsequent spill-over into large predators (Michel *et al.*, 2006). *M. bovis* infections have negative effects on the survival of endangered species in the Kruger National Park, Hluhluwe-iMfolozi Park and several adjacent private game reserves (Michel *et al.*, 2006). There is economic concern associated with the spill-over of infection back into domestic cattle particularly in trans-border wildlife reserves (Kriek, 2006; Munyeme, *et al.*, 2008) and trade in wildlife species between parks (Kriek, 2006; Michel *et al.*, 2006). There are also zoonotic risks especially in areas with a high incidence of HIV infection (Kriek, 2006). Control methods for *M. bovis* infection include tuberculin testing and

removal of positive animals in affected parks, pre-movement testing of translocated animals, and monitoring of existing populations (Michel *et al.*, 2006; Du Toit *et al.*, 2008).

1.12.7 The role of the badger as a maintenance host for *M. bovis* infection in cattle in the UK and Ireland

1.12.7.1 Badgers as a maintenance host for *M. bovis*

Badgers were first implicated in the transmission of *M. bovis* infection to cattle in 1971 when a badger with tuberculous lesions was found dead on a farm where bTB had recently been confirmed in cattle (Muirhead *et al.*, 1974). Future epidemiological studies showed that *M. bovis* infection in badgers lagged behind disease in cattle during 1970-1974 (Wilesmith *et al.*, 1982).

Several properties of *M. bovis* infection in badgers are consistent with a maintenance host (Cheeseman *et al.*, 1988; Corner, 2006; Kaneene and Pfeiffer, 2006); badgers survive for several years after infection (Clifton-Hadley *et al.* 1995b), infected females can reproduce (Delahay *et al.*, 2000) and recrudescence may follow stressful events (Gallagher *et al.*, 1998). Shedding of *M. bovis*-contaminated fomites occurs via several routes and may be intermittent (Clifton-Hadley *et al.*, 1993; Clifton-Hadley *et al.*, 1995b). *M. bovis* infection can prove fatal but does not affect the sex-age profile of populations (Cheeseman *et al.*, 1988). The social behaviour of badgers facilitates spread of infection through use of communal setts (Clifton-Hadley *et al.*, 2001), and latrines (Delahay *et al.*, 2007b), and by bite wounds (Gallagher *et al.*, 1976; Gallagher and Nelson, 1979; Clifton-Hadley *et al.* 1993; Delahay *et al.*, 2003; Jenkins *et al.*, 2008). Use of cattle resources may also allow for transmission of *M. bovis* to cattle (Tolhurst *et al.*, 2009). There is however, limited scientific evidence for the direct spread *M. bovis* from badgers to cattle.

1.12.7.2 Transmission of *M. bovis* from badgers to cattle

Transmission of *M. bovis* from badgers and cattle has been achieved experimentally (Little *et al.*, 1982b; Mahmood *et al.*, 1987a) and there is a possible link between increasing sett density and risk of bTB in cattle (Wilesmith, 1983). However, the strongest evidence for the role of badgers in bovine tuberculosis comes from large

scale badger culling trials in Steeple Leaze in Dorset (Little *et al.*, 1982a), Thornbury in Avon (Clifton-Hadley *et al.*, 1995b), East Offaly in Ireland (Martin, 1997; Ó Máirtín *et al.*, 1998; Eves, 1999) and in the 'Four areas' of Ireland (Griffin *et al.*, 2005a; Griffin *et al.*, 2005b) where sustained badger culling demonstrated a significant reduction in the numbers of cattle with *M. bovis* infection.

1.12.7.3 Government reviews of *M. bovis* transmission from badgers to cattle

Government reviews have concluded that badgers are a significant reservoir of *M. bovis* infection for cattle (Zuckerman, 1980; Dunnet *et al.*, 1986; Krebs *et al.*, 1997). The Krebs report (1997) recommended the establishment of the randomised badger culling trial (RBCT) led by an independent scientific group (ISG) (Krebs *et al.*, 1997; Bourne, 2007a). The ISG reported that in some instances, in reactively culled areas and the areas bordering proactively culled areas, badger culling resulted in an increase rather than a reduction in the incidence of herd breakdowns from *M. bovis* infection (Donnelly *et al.*, 2003; Donnelly *et al.*, 2006; Donnelly *et al.*, 2007). This increased disease incidence may have resulted from the perturbation of infection from disturbed badger populations (Woodroffe *et al.*, 2006a; Woodroffe *et al.*, 2006b; Jenkins *et al.*, 2007; Woodroffe *et al.*, 2008). As a result the culling of badgers in the UK was rejected as an effective means of controlling *M. bovis* infection in cattle. Culling as conducted in the RBCT is also considered unlikely to be a cost-effective method of bTB control in cattle (Jenkins *et al.*, 2010). The conclusions of the ISG have proven highly contentious (Bourne *et al.*, 2007b; King, 2007; More *et al.*, 2007) and considered contrary to studies in Ireland (Corner *et al.*, 2008a). Although initial reviews of the areas proactively culled in the RBCT suggested that any beneficial effects were not maintained (Jenkins *et al.*, 2010) recent findings suggest a longer-term beneficial effect (Donnelly, 2010). Political changes in the UK in 2010 are also likely to bring the subject under future review.

1.12.7.4 Alternatives to culling

As well as causing scientific debate as to its likely efficacy in controlling bTB in cattle, culling of badgers as a method of controlling tuberculosis in cattle in the UK is the subject of much strong public opinion (White and Whiting, 2000; DEFRA,

2006; Bennett and Willis, 2007a; Bennett and Willis, 2008) related both to badger protection and costs (Bennett and Cooke, 2006; Bennett and Willis, 2007b; Smith *et al.*, 2007). Alternative methods of control must therefore be found.

Farm husbandry methods have been considered to influence the transmission of *M. bovis* infections from badgers to cattle (Johnston *et al.*, 2005; Ward *et al.*, 2006; Reilly and Courtney, 2007; Ramírez-Villaescusa *et al.*, 2010). Badger latrines are one possible source of infection for cattle (Delahay *et al.*, 2007b) together with the use by badgers of farm resources for shelter (Cheeseman and Mallinson, 1981; Sleeman and Mulcahy, 1993; Garnett *et al.*, 2002) and food (Garnett *et al.*, 2003). The behaviour of sick badgers may facilitate the spread of *M. bovis* between the species (Muirhead *et al.*, 1974; Corner, 2006; Tolhurst *et al.*, 2009). Simple biosecurity measures such as electric fences prevent incursion by badgers into farm buildings (Tolhurst *et al.*, 2008; Ward *et al.*, 2010) but significant badger and cattle contact may still occur at pasture (Bohm *et al.*, 2009).

The development of a BCG vaccine for badgers (Lesellier *et al.*, 2006; Corner *et al.*, 2007; Corner *et al.*, 2008b; Lesellier *et al.*, 2008; Lesellier *et al.*, 2009b) will have implications for control of *M. bovis* infection in free-ranging badgers as well as for badger rehabilitation and release programmes. Large-scale field trials involve the use of intramuscular vaccination (Lesellier *et al.*, 2009a) and oral BCG vaccination (Corner *et al.*, 2009). Ecological considerations associated with vaccination of badgers against *M. bovis* have been discussed (Delahay *et al.*, 2003).

Other controls for *M. bovis* infection such as fertility control in badgers have been investigated but not seriously considered as practical options (White *et al.*, 1997; Tuytens and Macdonald, 1998; Smith and Cheeseman, 2002)

1.13 Protozoal diseases of badgers

1.13.1 *Toxoplasma* sp.

The majority of badgers (70%) in southern England (Anwar *et al.*, 2006) and Spain (Sobrino *et al.*, 2007) had serological evidence of *Toxoplasma gondii* infection but no clinical signs were reported.

1.13.2 Coccidiosis

Coccidiosis caused by *Eimeria melis* and *Isospora melis* has been reported occasionally in wild badgers causing poor growth in cubs (Newman *et al.*, 2000) with more severe infections resulting in deaths (Anwar *et al.*, 2000; Newman *et al.*, 2000). Co-infection with coccidial species was thought to result from contaminated latrines (Anwar, 2000). *Eimeria melis* and *Isospora melis* have been found in captive badger cubs and associated with clinical disease (diarrhoea and dehydration) resulting in mortality (A. Barlow *pers. comm.*), in contact animals were treated with toltrazuril (E. Mullineaux, unpublished data) as previously used in kittens and puppies (Lloyd and Smith, 2001). A *Giardia* species was identified as a cause of diarrhoea in badger cubs at a rehabilitation centre (VLA, 2009).

1.13.3 Trypanosomiasis (Trypanosomosis) and babesiosis

Trypanosoma pestanai was reported in Britain in Cornwall in 1974 (Pierce and Neal, 1974a) followed by reports of a *Theileria*-like parasite (Pierce and Neal, 1974b). This parasite was not *Babesia missirolii* previously reported elsewhere in Europe. Tick vectors, *Ixodes canisuga* and *I. hexagonus* were suggested as potential vectors (Pierce and Neal, 1974b). In a more recent study infection rates of 77% and 7.7% for *Babesia missirolii* and *Trypanosoma pestanai* respectively were reported over a three year period in badgers in Oxfordshire but infections were asymptomatic (MacDonald *et al.*, 1999).

1.13.4 *Sarcocystis* spp.

Sarcocysts, similar to *S. gracilis* found in roe deer (Odening *et al.*, 1994), were demonstrated in the tongue muscle of a badger in Germany but there are no reports of this parasite in Britain or Ireland.

1.14 Fungal and yeast infections

1.14.1 Dermatophytosis

While there are no clinical reports of dermatophytosis in badgers, the dermatophyte *Anthroderma melis* was isolated from a badger sett in 1977 in Czechoslovakia (Hancox, 1980). More recently, samples obtained in 1981 were classified as *Arthroderma olidum* part of the *Trichophyton terrestre* complex (Campbell *et al.*, 2006).

1.14.2 Histoplasmosis

Lymphatic histoplasmosis (Hancox, 1980), and histoplasmosis caused by *H. capsulatum* var. *capsulatum*, has been described causing granulomatous skin lesions and lymph node lesions in a wild badger in Austria (Bauder *et al.*, 2000).

1.14.3 Adiospiromycosis

Adiospiromycosis caused by *Emmonsia* (*Chrysosporium*) *crescens* was first described in badgers in Czechoslovakia in 1976 (Hancox, 1980). The infection is frequently found in the lung of badgers at post-mortem examination in common with findings in other digging mammals (Gallagher and Nelson, 1979; Borman *et al.*, 2009). In other Mustelidae such as otters infection can prove fatal (Simpson *et al.*, 2000). Adiospiromycosis granulomata may be confused with tuberculosis lesions post-mortem (Gallagher *et al.*, 1998).

1.15 Miscellaneous diseases of badgers

1.15.1 Neoplasia

Neoplasia appears to be rare in badgers with few cases identified at necropsy and reported in the literature; lymphosarcoma, benign tumours including cutaneous papilloma and liver haemangiomata (Gallagher and Nelson, 1979), mediastinal lymphoma (Mutinelli *et al.*, 2004) and a pelioid hepatocellular carcinoma (Salquero *et al.*, 2009) have been described.

1.15.2 Arteriosclerosis

Arteriosclerosis was reported in 26% of badgers in a post-mortem study but was considered the cause of death in only one of 70 cases (Gallagher and Nelson, 1979). Lesions of pulmonary ossification, which may lead to arteriosclerosis, have also been found post-mortem (Gallagher *et al.*, 1998).

1.15.3 Dental disease

Dental caries have been reported in healthy free-ranging badgers (Andrews and Murray, 1974) especially in older animals (Lewis, 1997b). Tooth wear and caries were found as the only obvious cause of emaciation in 7% of badgers in a post-mortem study (Gallagher and Nelson, 1979). Fractured teeth may occur during road traffic accidents (Lewis, 1997b) and have been associated with fatal osteomyelitis (Neal and Cheeseman, 1996). Teeth may frequently be fractured or damaged in badgers presented for veterinary examination necessitating treatment or removal before release while severe dental lesions justify euthanasia for welfare reasons (Cousquer, 2002; Mullineaux, 2003a).

1.15.4 Other reported disease conditions

Pneumonia, pyothorax and pleurisy, nephritis and enteritis (Gallagher and Nelson, 1979; Cheeseman *et al.*, 1988), endocarditis, cystic kidneys, renal calculi, and polyarthritis have been described at post-mortem examination (Gallagher and Nelson, 1979). Spinal arthritis, osteoarthropathies, and cataracts have been described in badgers presented for rehabilitation (Lewis, 1997b). Pharyngitis, tonsillitis and acute respiratory disease have also been reported (Neal and Cheeseman, 1996). Pituitary dwarfism has been diagnosed and described in a badger cub (Bexton, 2009).

1.16 Traumatic conditions affecting badgers

1.16.1 Road Traffic Accidents

RTA is considered the major cause of badger deaths (Gallagher and Nelson, 1979; Cheeseman *et al.*, 1987; Cheeseman *et al.*, 1988) even in populations with endemic tuberculosis (Gallagher and Nelson, 1979; Cheeseman *et al.*, 1988; Clifton-Hadley *et al.*, 1993). The number of RTA casualties may however be biased due to recovery of

badgers from the roadside in many studies (Cheeseman *et al.*, 1988). Such sample bias has also been reported for studies of other species such as otters (Simpson, 1997).

Proximity of setts to roads, poor road planning, and unfamiliarity of new roads all contribute to badger deaths (Neal and Cheeseman, 1996). Consequently, rural transport planning in some countries considers local badger populations in road building (Jaarsma *et al.*, 2007). Surprisingly, minor roads cause similar mortality as major trunk roads (van Langevelde *et al.*, 2009). Deaths from RTA peak during the spring and late summer (Davis *et al.*, 1987; Cheeseman and Neal, 1996). A study of road deaths collated by badger protection groups is presented in Chapter 3 (3.3.8). The seasonal prevalence of RTA deaths has been shown in other British mammals such as otters (Simpson, 1997). Grilo *et al.* (2008) found that badgers regularly used road culverts and underpasses where these were provided. It has been suggested that urban foxes alter activity patterns to avoid busy roads (Baker *et al.*, 2007).

1.16.1.1. Veterinary examination of badger road casualties

In veterinary practice methods of handling, examination, triage and treatment of badger road casualties have been described (Cousquer, 2005), however the author concentrates on concurrent injuries rather than those specific to RTA. The range of RTA injuries in badgers is similar to those sustained by dogs in similar collisions (Mullineaux, 2003a). Injuries to the jaw and teeth, long bones, vertebral column, spinal cord, and pelvis have been described (Lewis, 1997b; Mullineaux, 2003a). Chest injuries including haemothorax, pulmonary haemorrhage, pneumothorax and rupture of the diaphragm have been reported, together with rupture of the liver and spleen (Lewis, 1997b; Mullineaux, 2003a). The survival of some badgers in the wild after RTA is supported by radiographic evidence of healed fractures (Mullineaux, 2003a) and healed lesions of rupture of liver and spleen found at post-mortem examination (Gallagher and Nelson, 1979).

1.16.2 Trains

Deaths of badgers on railway lines have been reported (Neal and Cheeseman, 1996) but there are no reports of badgers being presented at veterinary surgeries following

such collisions, presumably because such events are always fatal (Neal and Cheeseman, 1996).

1.16.3 Illegal human activities - digging, baiting, snaring, shooting and gassing of badgers

Although the badger is a protected species (Protection of Badgers Act, 1992) illegal human activity may lead to badger injury and death (Meyer, 1986; Neal and Cheeseman, 1996; Mullineaux, 2003a).

Digging and baiting injuries may occur both to badgers and the dogs involved in this pursuit, including injuries to the head and limbs and differ in their presentation and necessary treatment from conspecific wounds described above (1.4) (Mullineaux, 2003a).

Badgers may be involved in accidental or intentional snaring (Mullineaux, 2003a). Snaring injuries involve the limbs, neck and abdomen of badgers and delayed pressure necrosis at these wound sites delay the release of such casualties (Lewis, 1997b; Mullineaux, 2003a).

Gassing and shooting of badgers has been reported (Neal and Cheeseman, 1996) but there are no clinical reports.

Badgers have been killed under licence in the various government control measures and related research programmes (1.12.7.3).

1.16.4 Poisoning

Malicious intent and a wide-ranging omnivorous diet make badgers susceptible to poisoning (Neal and Cheeseman, 1996; Mullineaux, 2003a). A case of metaldehyde poisoning in a badger has been reported (Cousquer, 2003).

1.17 Causes of mortality in adult badgers

Tuberculosis is the most important infectious disease of badgers in Britain but mortality is low (Cheeseman *et al.*, 1989). Road traffic accidents are the most

common cause of death in free-ranging studied badger populations accounting for around half adult badger losses (Gallagher and Nelson, 1979; Cheeseman *et al.* 1987; Cheeseman *et al.*, 1988; Neal and Cheeseman, 1996). The most comprehensive study of badger deaths (Gallagher and Nelson, 1979) included badgers involved in RTAs and animals killed for diagnostic purposes, and as such the sample population is considered biased (Neal and Cheeseman, 1996).

Starvation is been considered a significant cause of death in badgers (Cheeseman *et al.*, 1988; Clifton-Hadley *et al.*, 1993) especially in cubs during years of adverse climatic conditions (Neal and Cheeseman, 1996) and in adults affected with dental disease (Gallagher and Nelson, 1979).

1.18 Veterinary care of badgers

1.18.1 General veterinary information

Badgers have been included in descriptions of triage for wildlife in veterinary textbooks covering the common British wildlife species (Best and Mullineaux, 2003; Mullineaux, 2003a; Stocker, 2005). Specific text has additionally been published on the common problems in badgers (Lewis, 1997a, b, c), RTA injuries (Cousquer, 2005) and treatment of bite wounds (Keeble, 1999; Cousquer, 2002). Canine drug dose rates have been suggested for the treatment of medical conditions in badgers (Lewis 1997c; Mullineaux, 2003a; Cousquer, 2005) and the surgical techniques described are similar to those employed in domestic dogs (Mullineaux, 2003a). The importance of treating or removing damaged teeth prior to release has been stressed (Lewis, 1997c; Mullineaux, 2003a), together with the need to delay the release of badgers subjected to snare injuries to ensure that all potential damage caused by pressure necrosis has been fully assessed (Lewis, 1997c; Mullineaux, 2003a).

1.18.2 Veterinary treatment of bite wounds

Three techniques have been described for the treatment of bite wound injuries, two of which were considered to be successful; open wound management (Mullineaux, 2003a) and the use of topical wound dressings (Cousquer, 2002) and one less so; the suturing of the wounds (Keeble, 1999).

1.19 Rehabilitation and release of adult badgers

1.19.1 Rehabilitation organisations and guidelines

The major public organisations representing badger interests are the ‘Badger Trust’ in England and Wales and ‘Scottish Badgers’ in Scotland. The Badger Trust, together with other organisations (SWWR and RSPCA) published guidelines for rehabilitation and release in an attempt to standardise practices (Thomas *et al.*, 2002; SWWR *et al.*, 2003). General guidelines for rehabilitation centres have been produced (Miller, 2000; BWRC, 2007b) together with guidance more specifically for centres dealing with badger casualties (SWWR *et al.*, 2003). Guidance specifically relating to the prevention of transmission of *M. bovis* infections to cattle and other badgers following badger release has also been published (SWWR *et al.*, 2003; Mullineaux, 2003b).

1.19.2 Capture and transportation

Safe methods for the capture of British wildlife species have been described (Best and Mullineaux, 2003; Stocker, 2005). Specific recommendations for badgers have also been described including the use of graspers, dog-catchers and dog muzzles (Mullineaux, 2003b; SWWR *et al.*, 2003; Cousquer, 2005). Badgers should be transported in large coated mesh ‘crush’ cages specially designed for this purpose, although other solid containers are frequently used in emergency situations (Mullineaux, 2003b; SWWR *et al.*, 2003). In the RBCT 12% of badgers had cage related trapping injuries, of which only 1.8% were considered significant injuries; subsequent modifications to trap design reduced the incidence of problems (Woodroffe *et al.*, 2005). Covered cages are recommended in order to minimise stress (SWWR *et al.*, 2003). Stress in badgers during transportation has been assessed using haematological parameters (Mahmood *et al.*, 1988; Montes *et al.*, 2004) (1.6.5). Exertional myopathy associated with capture in badgers has also been described (Williams and Thorne, 1996). No clinical evidence of such effects has been observed in rehabilitation situations.

1.19.3 Maintaining badgers in captivity

In early experimental studies badgers in captivity were successfully fed ‘a mixture of meat and vegetables, warm beef stew and warmed honey soaked biscuits to tempt appetite’, with dog food eventually used as the predominant diet and chicken carcasses once a week (Little *et al.*, 1982b). Guidelines for rehabilitation and release centres suggest similar foodstuffs including dog and cat food, peanuts, fruit and fresh carrion (SWWR *et al.*, 2003). Dog food is suggested for the short-term feeding of badger casualties in veterinary hospitals (Mullineaux, 2003a). Suitable materials and dimensions for the construction of pens for badgers in captivity have been described (SWWR *et al.*, 2003). The ability of badgers to damage pens through chewing and digging makes steel structures most suitable within veterinary environments (Mullineaux, 2003a). Bedding materials such as straw, hay, and shredded paper have been suggested (SWWR *et al.*, 2003) together with the provision of a dark and secluded area for rest (Little *et al.*, 1982b; SWWR *et al.*, 2003, Mullineaux, 2003a).

1.19.4 Release of badger casualties

1.19.4.1 Fitness for release

The assessment of badger casualties for their suitability for release has been discussed (Best and Mullineaux, 2003; Mullineaux 2003a; SWWR *et al.*, 2003) and is considered further in the following chapters. In most instances adult badger casualties are released as soon as they are considered fit (SWWR *et al.*, 2003) although in other species (hedgehogs) a period in captivity prior to release has been shown to be beneficial (Molony *et al.*, 2006). There are no recommended body weights and condition scores for badgers prior to release as have been published for juvenile hedgehogs (Bunnell, 2002).

1.19.4.2 Identification prior to release

Badgers are often marked prior to release using tattoos bilaterally on the medial thigh area, sometimes in addition to microchips (Mullineaux, 2003a; SWWR *et al.*, 2003). Tattoo numbers are issued by the Badger Trust and tattooing is carried out under licence from Natural England (1.21).

1.19.4.3 Release methods

The different release methods from captivity have been described (Llewellyn, 2003) and specifically for badgers (SWWR *et al.*, 2003). Adult badgers should be ‘hard released’ where they were found, from dusk onwards when badgers are most active and roads are quieter (SWWR *et al.*, 2003; Mullineaux, 2003a). Release sites may be influenced by potential effects on other species, such as birds (Roper, 1997) and hedgehogs (Sainsbury *et al.*, 1996; Young *et al.*, 2006). There are no post-release studies of individual rehabilitated badgers but there are successful reports of groups moved to badger-free areas in Holland (Mulder, 1996) and translocation to areas of low badger density in England (Brown and Cheeseman, 1996).

1.20 Health and safety considerations in badger rehabilitation

In common with many other wildlife species the risks associated with handling badgers include; bites, scratches and zoonotic infection (Lewis, 1997c; Best and Mullineaux, 2003; Mullineaux, 2003a; Cousquer, 2005). Handling techniques such as scruffing of badgers, use of dog-catchers and gauntlets have been recommended (Mullineaux, 2003a; SWWR *et al.*, 2003). ‘Baskerville’-type dog muzzles should be used even when badgers are moribund or sedated (Mullineaux, 2003a; Cousquer, 2005).

Suitable risk assessment should be undertaken at wildlife centres and veterinary practices dealing with wildlife casualties (Cooper, 2003). Veterinary surgeons should not attend badger RTAs alone, and when at the roadside should use warning triangles and car hazard lights and wear reflective clothing (Cousquer, 2005). Precautions to protect staff against disease risks include vaccination against both rabies (Trevejo, 2000) and tuberculosis (Mullineaux, 2003a). Although the risk of *M. bovis* infection from animals is considered to be very low (de la Rua-Domenech, 2006) occupational infection has been suggested (Shrikrishna *et al.*, 2009; Twomey *et al.*, 2010). Additional precautions to protect staff from risks of *M. bovis* infection include the use of latex gloves when handling badgers or any body fluids, appropriate surface cleaning and disinfection, and restricted invasive surgical procedures and post-mortem examination (Mullineaux, 2003a).

1.21 Legal considerations

1.21.1 Legislation concerning badgers

Legislation covering mammals within the British Isles is extensive and includes International, European, Scottish, Welsh, and Northern Irish laws (BWRC, 2007c; Mitchell-Jones *et al.*, 2008). The badger is a protected species in the UK, the Irish Republic and many other European countries. Elsewhere, the badger is considered as small game or a pest, with hunting regulated by closed seasons (Griffiths and Thomas, 1993). Legal considerations affecting the capture, treatment and release of British wildlife casualties (Cooper, 2003; Cooper and Cooper, 2006; BWRC, 2007c) and specifically badgers (Harris *et al.*, 1994; SWWR *et al.*, 2003; Badger Trust, 2007) is also available and is referred to in the summaries below. For the purposes of this review information is limited to that affecting badgers in England and that especially relevant to badger rehabilitation and release. The legislative Acts, listed below, are far reaching and aspects considered below are those specifically relating to the various stages of the rehabilitation and release process.

- Abandonment of Animals Act 1960
- Animal Health Act 1981
- Animal Welfare Act 2006
- Health and Safety at Work Act 1974
- Medicines Act 1968
- Protection of Animals Act 1911
- Protection of Animals (Anaesthetics) Acts 1954 and 1964
- Protection of Badgers Act 1992
- Public Health (Control of Diseases) Act 1984
- Public Health (Infectious Diseases) Act 1988
- Veterinary Medicines Regulations 2009 SI 2297
- Veterinary Surgeons Act 1966 (as amended 2002)
- Welfare of Animals (Transport) Order 1997
- Welfare of Animals in Transport order 2006
- Wild Mammals (Protection) Act 1996

- Wildlife and Countryside Act 1981 (as amended)
- Zoo Licensing Act 1982 (as amended 2002)

1.21.2 Capture and rescue of badger casualties

Permission should be gained from the land or property owner to access badger casualties found on private land. There is no right of ownership of wild animals until taken into captivity at which point the finder becomes the 'owner'. Badgers in common with other wildlife species are protected under the Wildlife and Countryside Act, 1981 (WCA) that allows wildlife to be taken for treatment with the intention of eventual release. Badgers are additionally protected under Schedule 6 of the WCA which limits the methods of 'taking or killing' of the species which could in theory limit the use of traps to capture injured badgers, except under licence from Natural England.

The Protection of Badgers Act, 1992 specifically exempts the taking of 'disabled' badgers for treatment provided the animal has not been injured by the finder or the injury was 'unavoidable as an incidental result of lawful action' (thus exempting those who unintentionally cause RTA injuries to badgers).

The Welfare of Animals (Transport) Order, 1997 has specific exemptions for 'the transport of animals which does not take place in connection with an economic activity and to the transport of animals directly to or from veterinary practices or clinics, under the advice of a veterinarian', thus the transport of casualty badgers could be considered to be uncontrolled by such legislation. Transportation of the casualty to a wildlife rescue centre or from a centre for release may however be covered by the Order. The general principles of the Order should be considered fully when transporting casualties, these stipulate; the construction and use of receptacles in which the animals are transported in respect of their suitability for the species, ability of the animal to turn, stand and lie down, provision of suitable ventilation and bedding, appropriate provision of food and water, a means of inspection, and that the animal is not transported within sight of a natural predator. During any capture and handling welfare legislation as described below, must also be adhered to.

1.21.3 Keeping and treatment of casualties in captivity

The WCA, 1981 gives provision for animals to be kept in captivity for treatment until no longer disabled. The Act also gives provision for animals that cannot be released, to be killed for welfare reasons. The Protection of Badgers Act 1992 gives additional provision for the treatment and euthanasia of sick and injured badgers. Whilst in captivity (and during capture and transportation) the welfare of mammalian wildlife casualties, including badgers, in terms of the prevention of ‘unnecessary suffering’ is protected by the Protection of Animals Act 1911, the Wild Mammals (Protection) Act 1996 and the Animal Welfare Act 2006. Veterinary treatment of badgers and other wildlife is covered by the Veterinary Surgeons Act (VSA) 1966 which limits the treatment of wildlife casualties by lay people to emergency life-saving care and alleviating suffering. All medical and surgical treatment must be provided by a veterinary surgeon registered with the RCVS. Amendments under schedule 3 of the VSA (2002) allow for medical treatments and minor surgery of wildlife, in common with other species, to be carried out by a suitably-trained and Registered Veterinary Nurse (RVN).

Additionally the RCVS ‘Guide to Professional Conduct’ (RCVS, 2008) and BVA/RSPCA ‘Memorandum of agreement’ make it a requirement of veterinary surgeons in practice to provide emergency care to all species including wildlife, as described earlier (1.1.2.1). The Medicines Act 1968 and the Veterinary Medicines Regulations 2009 control the use and choice of medical treatments. Few medicines are licensed for use in ‘exotic’ species or wildlife so the prescribing ‘cascade’ as interpreted in the RCVS ‘Guide to Professional Conduct’ (RCVS, 2008) must be adhered to. If the wild animal is considered to have an ‘owner’ consent for the use of ‘off-label’ products should be obtained. The Protection of Animals (Anaesthetics) Acts 1954 and 1964, require the use of anaesthetics for painful procedures.

The Animal Health Act 1974 makes provision for the notification of animals suspected of having a disease listed as ‘notifiable’ under the order. The order states that: ‘any person having in their possession or under their charge an animal affected or suspected of having one of these diseases must, with all practicable speed, notify that fact to a police constable’; in practice reporting is made to the local office of

DEFRA. Cases of tuberculosis (*M. bovis* infection) in badgers and other wildlife fall under this legislation though reporting is usually limited to infection in cattle and deer. Veterinary practices and rehabilitation centres must work under the Health and Safety at Work Act 1974 and as such should have risk assessments relating to the handling and treatment of wildlife and suitable training of staff to prevent risk, disease and injury. Some of these considerations are described above (1.20). Specific precautions relating to the zoonotic risk of *M. bovis* infection in badgers have been described (Mullineaux, 2003a).

The Zoo Licensing Act 1981 applies to rehabilitation centres open to the general public for seven or more days in a twelve month period and involves the inspection of animal husbandry, record keeping and veterinary care at the facility; many rehabilitation centres reliant on public funding fall into this category. Badgers are not considered to be 'dangerous' under the Dangerous Wild Animals Act 1976 (as amended).

1.21.4 Release of casualties

The Abandonment of Animals Act 1960 makes it an offence to abandon an animal and cause unnecessary suffering. Wildlife species should not therefore be released unless they are able to both survive and not endanger other wildlife. Other welfare legislation as described above would also apply at this stage. Badgers are often tattooed prior to release and this can only be carried out legally under the Protection of Badgers Act 1992 under licence from Natural England who 'Under Section 10(1)(c) of the Act have authority to issue licences to take badgers for the purpose of ringing and marking and to mark such badgers or attach to them any ring, tag or marking device as specified in a licence'. Transportation of a casualty to a release site should not cause additional injury or unnecessary suffering, and may be influenced by The Welfare of Animals in Transport Order 2006 as above.

1.22 Aims of this study

This review of literature illustrates the limited information available to those involved in the treatment, rehabilitation and release of badger casualties. It is inevitable that British wildlife casualties, including badgers, will continue to be presented to veterinarians in general practice. Since such veterinary care is required for legal, welfare and ethical reasons, it is essential that veterinary knowledge of these species increases to provide the best possible treatment for these animals committed to our care.

This study aims to determine the reasons why badgers are presented as casualties to veterinary surgeries and the factors, clinical and otherwise, that determine their successful release.

Chapter 2

Materials and methods

2.1 Study population of badgers

Adult badger casualties were found by the general public and reported to either Secret World Wildlife Rescue (SWWR), a wildlife rescue group in East Huntspill, Somerset offering 24 hour emergency assistance, or to Somerset Badger Group. Rarely casualties came directly to Quantock Veterinary Hospital (QVH).

SWWR cares for approximately 4,000 wildlife casualties per annum including most British species (S. Kidner *pers. comm.*). Since badgers are found in their greatest numbers in this part of the country (Wilson *et al.*, 1997; Delahay *et al.*, 2008) the centre cares for large numbers of adult badger casualties and is one of the few centres in the UK where badger cubs are reared.

Badgers were captured without chemical restraint (SWWR *et al.*, 2003) and transported in badger crush cages covered with tarpaulin. Badgers were examined and treated at QVH in Bridgwater, Somerset. All adult badgers presented to QVH and/or SWWR between November 2002 and July 2006 were included in the study.

2.2 Data record sheet

A standard record sheet was used (Appendix 1.1) similar to those used by Central Science Laboratory (CSL) (now part of the Food and Environment Research Agency, FERA) at Woodchester Park (Appendix 2.1) to allow data comparison. Veterinary staff at QVH and staff at SWWR used detailed guidance notes (1-7) for data collection when the author was not present (Appendices 1.1.1-7).

Data recorded (Appendix 1.1)

2.2.1 Reference number

The case reference number allocated specifically to badgers in the study.

2.2.2 Secret World log number

The log number allocated by SWWR to all wildlife casualties on admission independent of species.

2.2.3 ID chip number

All animals presented were scanned for microchips on admission in case they had previously been treated or reared at a wildlife rescue centre. Medial thigh tattoos are the recognised and more common form of identification in adult badgers.

2.2.4 RSPCA log number

Where casualties were treated on behalf of the RSPCA.

2.2.5 Tattoo number

Casualties were tattooed under licence from Natural England to the medial aspect of both thighs in accordance with guidelines (SWWR *et al.*, 2003) before release.

2.2.6 History

Completed by those dealing with the case based upon questioning of the finder, information included (Appendix 1.1.1).

2.2.6.1 Geographical location

Ordinance survey (OS) grid reference or Global Positioning System (GPS) reference was recorded to ensure adult badger casualties are released where they are found according to accepted protocol (SWWR *et al.*, 2003).

2.2.6.2 Location in which found

For example; in a field, wood, certain type of building, garden, or at the roadside.

2.2.6.3 Reason for presentation

For example; RTA, trapped, snared, shot, wounds

2.2.6.4 Clinical information

The presenting signs as described by the veterinary surgeon

2.2.7 Admission date

The date of admission to QVH or SWWR, whichever was first, was recorded.

The following records could only be made with badgers adequately anaesthetised.

2.2.8 Length

The length of the badger was recorded in millimetres, with the animal in dorsal recumbency, from tip of nose to last coccygeal vertebra (Appendix 1.1.1).

2.2.9 Weight

The weight of the badger was measured using electronic dog weighing scales accurate to +/- 10 grams.

2.2.10 Age

Badgers were confirmed to be 'adult' using the criteria provided by Woodchester Park (Appendix 1.1.2).

2.2.11 Sex (M / F)

Animals were classified as 'male' or 'female' (Appendix 1.1.4).

2.2.12 Body condition

Body condition was classed on a four-point scale, poor-very good (Appendix 1.1.3).

2.2.13 Female reproductive classification

Female animals were classed according to their reproductive condition including evidence of pregnancy or lactation (Appendix 1.1.4).

2.2.14 Dentition chart

A standard canine veterinary dental chart was adapted for use in adult badgers (Appendix 1.1) and dental abnormalities recorded (Appendix 1.1.5).

2.2.15 Tooth wear assessment

Tooth wear graded using the five-point scale, 0-1 (Appendix 1.1.6).

2.2.16 Bite wound recording

Bite wounds were classified according to body position, number, chronicity and size (Appendix 1.1.7)

2.2.17 Clinical examination

The important findings of a full clinical examination and all clinical test results including culture of bite wounds, blood sample results and radiography were documented.

2.2.18 Treatment given

A record was made of all treatments given and the immediate treatment plan.

2.2.19 Outcome (today)

The immediate outcome for the animal was recorded, outcome options were: released, hospitalised (at QVH), rehabilitated (at SWWR), euthanased, or died.

2.2.20 Outcome long-term (date)

The ultimate outcome options were: released, euthanased or died. In many cases this final information was obtained from SWWR hospital sheets

2.3 Clinical Triage

On admission badger casualties were assessed using the ‘triage’ principles described in reference wildlife textbooks (Best and Mullineaux, 2003; Vogelnest, 2008). A decision was made, with consideration to medical condition, badger ecology and the availability of suitable facilities for it’s care whether the badger could be returned to the wild (Figure 2.1). If eventual release was not possible the badger was euthanased for welfare reasons immediately following admission. If eventual release was possible the animal either received first aid treatment in order to stabilise its condition or it was anaesthetised to allow a more thorough clinical examination and any necessary ancillary tests. Eventually, casualties were considered stable enough to move to SWWR and for some individuals on to be released. Re-assessment was made at each stage questioning the likelihood of successful release and euthanasia was carried out as necessary. The possible scenarios of this process are illustrated in Figure 2.2. Not all cases moved through this process in a uniform way, some badgers returned to QVH following a period of time at SWWR for more diagnostic tests to be performed or for repeated periods of hospitalisation.

Figure 2.1 Quantock Veterinary Hospital criteria for the rehabilitation and release of adult badger casualties

Criteria considered necessary for an eventual successful release of an adult badger casualty

(Mullineaux, 2003a; Best and Mullineaux, 2003; SWWR et al., 2003)

The aim of rehabilitation of wildlife casualties is to release the casualty back into the wild, as quickly as is possible, in a condition that allows it to function normally and have a chance of survival equal to that of other free-ranging members of its species. In the case of badgers (*Meles meles*) the following should be considered when making a decision to treat a casualty, if these considerations cannot be satisfied the animal should be euthanased.

Animal dependent factors

Suitable age of animal:

- Age is based upon physical size, dentition and tooth wear.
- Old animals may be at end of natural lifespan and euthanasia may be the most humane course of action.
- Dependent juveniles require specialist care, feeding, rehabilitation and release and these facilities must be available.

Sex of animal:

- Release of female animals may be influenced by pregnancy or lactation and injuries affecting the animals' ability to carry out these processes normally.
- Sex of juvenile animals may influence availability of suitable release groups.

Natural history of the badger:

- Released animals need to be able to carry out basic functions such as feeding, running, digging, defending territory and reproducing successfully in the wild. Any long-term disabilities must not compromise these basic functions.

Body condition:

- Is an indicator of the chronicity of problems.
- May be treated if genuine starvation (e.g. dependent cubs) or treatable injury in otherwise healthy animals (e.g. territorial wounding in young animals).
- May be an indicator of chronic disease (e.g. *M. bovis* infection) or chronic untreatable injury (e.g. long standing orthopaedic injuries) and such animals should be euthanased.

Health status:

- Longstanding persistent abnormalities may be incompatible with normal function ('see Natural history'), in particular injuries to the snout and jaw and the limbs.
- Consideration should be given to diseases posing a risk to other badgers following release or of a zoonotic risk to staff during captivity.

Prognosis for recovery:

- Ability to successfully treat the condition.
- Considerations to include the likely success of treatment.
- The ability to provide the high level of medical and surgical care required in 'performance' animals such as wildlife casualties. Veterinary skills, facilities, time and financial support may all be factors for consideration.
- The duration of treatment and therefore time in captivity.
- The practicality of treatment, including the welfare of the casualty and safety of staff.

Psychological status:

- Assessment should be made of the animal's normal responses to people, the environment, other animals and other badgers.
- Psychological status should be continually assessed throughout the rehabilitation process and prior to release.

Facilities dependent factors**Facilities for short-term care**

- Availability of suitable secure hospital facilities away from domestic animals.
- Availability of suitably trained and competent staff.

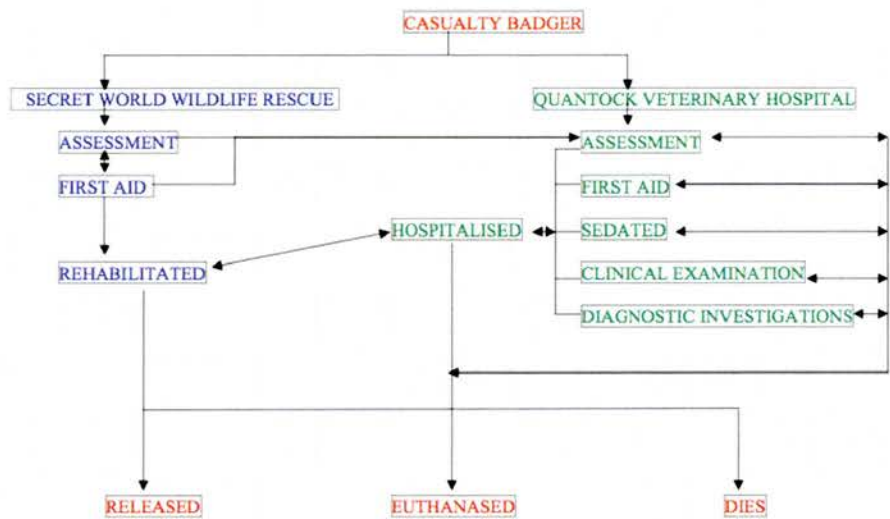
Facilities for longer-term treatment and aftercare (rehabilitation):

- Availability of suitable badger specialist facility
- Availability of suitably trained and competent staff.
- Consideration of the likely period of time in captivity.
- Requirements depend upon age of casualty and medical problems

Availability of release sites:

- Adult badgers are hard released exactly where found, a knowledge of the site where found (grid reference or good geographical location) is therefore necessary
- Cubs require specialist soft release in groups
- Suitable sites must be available

Figure 2.2 Triage and assessment process



2.4 Anaesthesia

The anaesthetic combination used was medetomidine hydrochloride (Domitor®, Pfizer Ltd., Sandwich, UK) at 40 µg/kg combined with ketamine hydrochloride (Narketan 10®, Vetoquinol UK Ltd., Buckingham, UK) at 5.0 mg/kg, by intramuscular injection in the same syringe. Intramuscular injections could usually be given through the bars of a wire badger cage without further restraint, although in some cases the crush facility was used to further restrain the badger. In all cases, comatose or anaesthetised, a plastic mesh muzzle (Baskerville muzzle®, The Company of Animals, Chertsey, UK) was placed on the badger before handling. Additional anaesthesia, using sevoflurane (Sevoflo®, Abbott Animal Health Ltd., Maidenhead, UK) in oxygen by mask or via endotracheal intubation using a suitable gas anaesthetic circuit, was administered as necessary. Anaesthesia was monitored by a trained veterinary nurse (usually RVN) using a stethoscope, pulse oximeter and anaesthetic record sheet. During longer procedures additional anaesthetic monitoring used electrocardiograph, respiratory and carbon dioxide monitors, and temperature probes. The medetomidine component of the anaesthetic combination was reversed using atipamazole hydrochloride (Antisedan®, Pfizer Ltd.) at a dose of 200 µg/kg by

intramuscular injection. Badgers recovered from anaesthesia in covered holding cages kept at room temperature in a quiet environment. Euthanasia, where necessary, was carried out whilst the animal was still anaesthetised.

2.5 Diagnostic tests

Diagnostic test were performed as only clinically necessary prior to February 2004, and from February 2004 radiography, biochemistry and haematology, *M. bovis* serology and culture of wound swabs was performed on all casualties.

2.5.1 Plasma biochemistry

Blood samples were collected into lithium heparin containers via jugular venepuncture and analysed within 30 minutes using a standard 12 test biochemistry profile (Vettest®, Idexx Laboratories, Wetherby, UK) and electrolyte measurements made on a standard analyser (Vetlyte®, Idexx Laboratories) (Appendix 2.2) both validated for badger plasma. In-house quality assurance tests were completed on a monthly basis (Appendix 2.3) in conjunction with Idexx Laboratories, and as part of routine veterinary hospital procedures. Plasma calcium concentrations were adjusted using the method described in Appendix 2.4.

2.5.2 Haematology

Full differential blood cell counts on EDTA samples, were undertaken by Idexx Laboratories (Appendix 2.5).

2.5.3 Reference ranges for interpretation of blood tests

Two reference ranges were used for interpretation of badger biochemical and haematological tests (Appendix 2.6); canine reference intervals for haematology (Idexx Laboratories) and biochemistry and electrolytes (Vettest® at QVH) at the time of study, and badger reference ranges from Woodchester Park (Mullineaux, 2003a).

2.5.4 *M. bovis* serology

Whole blood samples were collected by jugular venepuncture and serum separated and stored at -20 C until analysed at VLA Langford using the badger bTB ELISA

(‘Brock test’). Adult badger casualties were not normally tested for evidence of *M. bovis* infection when following the accepted rehabilitation guidelines (SWWR *et al.*, 2003), samples were therefore processed retrospectively so results did not influence the clinical decision.

2.5.5 *M. bovis* culture of bite wounds

Swabs from large bite wounds were transported in charcoal media and cultured for *M. bovis* at FERA, York. *M. bovis* strains were spoligotyped. Bite wounds were not cultured for routine bacteriology until 2009 because of health and safety restrictions.

2.5.6 Radiography

Before February 2004 radiographs were taken as an appropriate diagnostic tool. From February 2004 two radiographs were taken of the whole of each badger at exposure settings that best illustrated the majority of tissues. A dorso-ventral (DV) radiograph was taken to include the head, forelimbs and chest and a ventro-dorsal (VD) view of the abdomen, pelvis and hind-limbs. Further radiographs were then taken of specific abnormalities as required.

2.5.7 Urinalysis

Urinalysis was not carried out because of health and safety concerns.

2.5.8 Post-mortem examination

Post-mortem examinations were not carried out because of health and safety concerns.

2.6 Medical and Surgical treatments

The rationale for treatment was extrapolated from small animal veterinary medicine and in most cases canine drug doses were used (Mullineaux, 2003a; Ramsey, 2008) following the prescribing cascade (RCVS, 2008). Intravenous fluid therapy and medication including analgesic drugs were employed in the initial first aid treatment. The choice of long-term medication was influenced by ease of administration; ensuring compliance, minimising stress to the animal, and ensuring the safety of staff. Intramuscular preparations were preferred to intravenous or oral medication.

2.6.1 Treatment of parasitic infections

Endoparasities were presumed to be present and many animals had obvious ectoparasitic burdens. The decision not to treat concurrent parasitic infestations, unless debilitating, has been discussed elsewhere (Best and Mullineaux, 2003) and is based upon the presumption that treatment of ‘normal’ parasitic burdens without clinical consequences is both unnecessary and possibly not in the animal’s best long-term interest with respect to maintaining longer term immunity. Parasite burdens and any evidence of their clinical effects on casualties were monitored during captivity.

2.6.2 Treatment of bite wounds

Bite wounds were managed as open wounds according to the protocol described in Appendix 2.7. Any antibiotic was selected with consideration of any concurrent problems, and given for as long as clinically required.

2.7 Hospitalisation, rehabilitation and release

2.7.1 Hospitalisation at QVH

Badgers in the study were hospitalised at QVH for the shortest possible period in stainless steel secure kennels as far away from other patients as was practical. Bedding (paper and blankets) was provided to allow the animal to bury itself and hide and the kennel door was covered in order to provide a darkened environment. Observation, noise and handling were kept to a minimum and made as unobtrusive as possible. Food, usually tinned and dried dog food in the short-term, and water in a heavy dog bowl were provided. Standard hospitalisation forms were used to record clinical parameters and medical treatment (Appendix 1.2).

2.7.2 Rehabilitation at SWWR

Badger casualties at SWWR were kept in individual secure pens isolated from all other animals. Straw, blankets, and shredded paper were provided as bedding material. Badgers were provided with an omnivorous diet including dead chicks, chicken and dog food (SWWR *et al.*, 2003). Food and water intake, medication and general demeanour were recorded daily (Appendix 1.3). Badgers not progressing as expected were discussed with a veterinary surgeon and re-examined as necessary

using the standard triage criteria. Badgers would be confirmed fit for release by a veterinary surgeon prior to release (Figure 2.1) as well as meeting all other criteria (Figure 2.3).

2.7.3 Release

Once satisfying the release criteria (Figures 2.1 and 2.3), badgers were released back into the wild at night at the capture site without food, water or other support, referred to 'hard release' (Llewellyn, 2003; SWWR *et al.*, 2003). Bilateral medial thigh tattoos, using numerical codes provided by the Badger Trust, were applied under licence from Natural England prior to badger release.

Figure 2.3 Secret World Wildlife Rescue criteria for release

<p>Secret World Wildlife Rescue criteria for adult badger release (<i>Pauline Kidner pers.comm.</i>)</p> <ul style="list-style-type: none">○ Badgers are only released once medical problems have fully resolved and the animal is considered physically fit.○ Food and water intake is assessed daily and recorded on hospital sheets. Animals are only released when eating on a regular basis (every night).○ Cameras allow remote monitoring of behaviour and movement and secure facilities allow animals to be moved along corridors to directly assess locomotion and behaviour; veterinary attention is sought if abnormalities are detected.○ All badgers are anaesthetised a few days prior to release in order to identify them in the future through the use of tattoos, this allows a physical examination to take place.○ Badgers are returned to the exact site in which they were found. Animals are released at night at a time when roads are likely to be least busy (on country roads this is usually around 10 - 11 p.m. and in busy towns possibly as late as midnight to 1 a.m.). In busy towns releases ideally take place from Sunday to Thursday rather than at the weekend.○ Trained staff only to carry out releases. Animals are transported by road in covered carrying cages. On arrival at the release site the cover is first removed to allow the animal to orientate itself. Side opening cages allow the badger to leave the cage in its own time.
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2.8 Health and Safety considerations

In common with all wildlife species, handling badgers creates potential health and safety risks for staff including bites, scratches and the risk of zoonotic infections, most importantly *M. bovis* infection. Health and safety of staff at QVH dealing with the badgers included (Mullineaux, 2003a):

2.8.1 Suitable training

Training of staff in handling badgers and other wildlife was included as part of general staff health and safety induction, training and review. Training included correct handling techniques for badgers and use of appropriate safety equipment.

2.8.2 Risk assessments

Risk assessments were put in place for all staff according to their roles and responsibilities and tasks performed.

2.8.3 Standard Operating Procedures (SOP)

SOPs were put in place and task assessments completed with respect to health and safety.

2.8.4 Vaccination of staff

Staff members were vaccinated, where appropriate, with BCG vaccine.

2.8.5 Equipment for the safe handling of badgers

Trapping cages with crush facilities, gauntlets and muzzles were provided, sedative/anaesthetic drugs were used where appropriate.

2.8.6 Use of personal protective equipment (PPE)

Disposable aprons, latex gloves, and masks were used to avoid contact with body fluids as appropriate.

2.8.7 Avoidance of unnecessary exposure to potentially infectious body fluids and tissues

Special care was taken when handling urine, faeces, saliva and open wounds. PPE was used. Draining of body cavities was avoided and when necessary implemented using closed systems only. Badger post-mortem examinations were not carried out.

2.8.8 Use of appropriate cleaning agents

All surfaces and equipment were fully cleaned once all procedures had been completed. Where the risk of contamination was high Lysol BP disinfectant was used at dilutions (1 part to 39 parts water) for the required contact time (1 hour) for activity against *M. bovis*.

Similar Health and Safety protocols were in place at SWWR for their staff and volunteers. Members of the general public contacting SWWR regarding sick or injured badgers were advised under no circumstances to handle the animals and to wait for trained assistance.

2.9 Data Analysis

Data were analysed using Microsoft Excel 2003 for Mac.

Chi-squared tests were used to examine categorical data where overall sample size was 40 or over and smallest expected value was greater than five (Kirkwood and Stern, 2003). Normal distribution tests were used for comparison of two means where sample sizes were greater than 30, otherwise a Student's t test was used (Kirkwood and Stern, 2003), $P < 0.05$ was taken to indicate statistical significance.

Chapter 3

Demographics and reasons for presentation

3.1 Introduction

There is limited information regarding when and why wildlife casualties are admitted to veterinary surgeries and wildlife rescue centres (Best, 1999; BWRC, 2000; Molony, 2007). Such information aids the triage process for determining those casualties that are likely to be successfully rehabilitated and released back to the wild and those that carry a poor prognosis and should be euthanased at the earliest opportunity for welfare reasons (Best and Mullineaux, 2003; Molony, 2007). Recognition of abnormal trends in presentations contributes to veterinary wildlife disease monitoring programs (Duff, 2003) and is valuable to ecologists, especially those concerned with the human animal interface and in the assessment of disease risk to man and other animals (Wobeser, 2007). Such information may also be used to limit the influences of human action on disease and trauma in wildlife, for example in managing the use of overhead electrical cables to prevent bird mortality (Wobeser, 2007), or in road planning (Ramsden, 2003).

Badgers are not uncommonly presented to wildlife rescue centers (BWRC, 2000) especially in those areas of the country such as the south west of England where their population density is high (Wilson *et al.*, 1997; Delahay *et al.*, 2008). This chapter describes the circumstances under which adult badger casualties were presented for treatment and rehabilitation and the demographics associated with this population.

3.2 Materials and methods

Detailed records were made of all badger casualties presented to QVH or SWWR between November 2002 and July 2006 as described in Chapter 2.

The date of admission to QVH or SWWR (whichever was first) was recorded to allow seasonal and annual trends to be identified. A detailed history was taken from the finder of where, and under what circumstances, the badger was found (Appendix 1.1.1). Finders were asked to describe the location in which the badger had been found. If clarification was required examples were provided such as; 'in a field', 'in a wood', 'in a certain type of building', 'in a garden', 'at the roadside'. Finders were also asked to give the main reason for presentation of the casualty badgers, which in

most cases was their reason for seeking professional assistance. The data categories were selected to include all the likely reasons for the badger casualty presentations and to be similar to those in a proposed RSPCA computer database for wildlife casualties shown in Table 3.1 (A. Grogan, RSPCA *pers. comm.*). Many badgers had several presenting signs but in all cases the over-riding reason for the finder contacting the rescue centre could easily be established. Some animals had no obvious clinical signs and the reason for presentation was that they were just in a place that was abnormal or inconvenient for the finder. Dead badgers were excluded from the study.

Table 3.1 Data categories for the reason for initial presentation of adult badger casualties

Neurological signs (for example circling) (CNS)
Caught / entangled in material
Collapsed / recumbent
Lame
Paraplegic / dragging legs
Presumed / known road traffic accident (RTA)
Thin
Wounds (if nothing else)
No signs identified, just in the wrong place

Following admission and in most cases after sedation or anaesthesia (2.4), basic data included the length from tip of nose to final coccygeal vertebra (Appendix 1.1.1) and live weight of the animal in kilograms using electronic dog weighing scales. Animals were confirmed as adult using the criteria previously described (Appendix 1.1.2). The sex of the animal was determined and the reproductive status of female animals described (Appendix 1.1.4). Tooth wear was assessed using a five-point scale (Appendix 1.1.6) in an attempt to age the animal; dental disease and damage is considered in Chapter 4.

Early analysis of data and work by other authors (Lewis, 1997b; Mullineaux, 2003a; Cousquer, 2005) had suggested RTA to be a common reason for admission of badger casualties. Approaches to the Badger Trusts provided additional data from some of

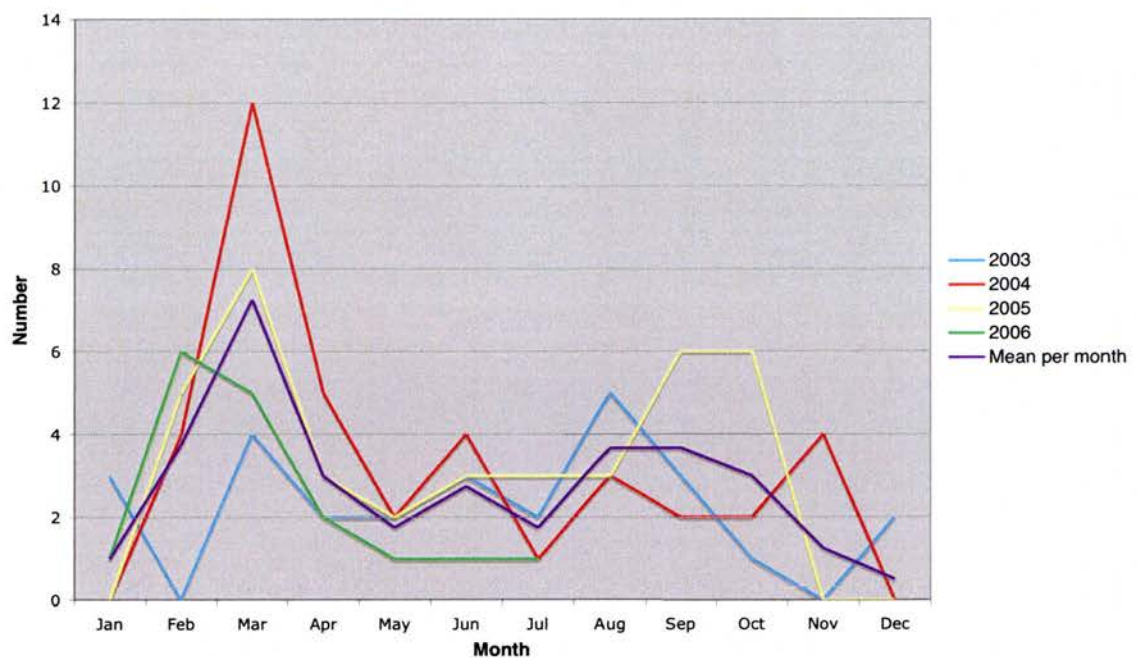
their members relating to trends in badger RTAs for the time around the study period 2003-2006. Scottish Badgers provided similar information from north of the border.

3.3 Results

3.3.1 Month of admission

The month and year in which 123 badger casualties were admitted between November 2002 and July 2006 was recorded. Seasonal trends in presentations were seen throughout the complete years of study (Figure 3.1).

Figure 3.1 Seasonal trends in the month of presentation of adult badger casualties during the study years (2003-2006)



3.3.2 Location in which adult badgers were found

Members of the general public provided information regarding the location in which 115 badgers were found (Table 3.2). The sex of animals found had been recorded in 102 cases where the location in which the casualty was found was also known (Figure 3.2). Badgers found in buildings were significantly more likely to be male than those found in other locations (domestic buildings plus farm buildings $P < 0.001$; farm buildings only $P < 0.01$). Female badgers were more commonly found at the roadside than in other locations although this difference was not statistically significant.

The month of presentation was considered for those casualties where the location in which they were found was known. Seasonal trends in the places in which these badgers were found are shown in Figure 3.3. Badgers were significantly more likely to be found in farm buildings ($P < 0.001$) during March and at the roadside in February ($P < 0.05$) and June ($P < 0.05$).

Table 3.2 Adult badger casualties classified according to the locations in which they were found

Site	Description of location and examples recorded	Number (%)
Field	<i>Badgers found in open fields usually by farmers or walkers.</i>	8 (7.0%)
Road	<i>Badgers found at the roadside usually by people travelling in cars, in some instances these were presumed by the finder to have been hit by their own vehicle.</i>	42 (36.5%)
Garden	<i>Badgers found in domestic gardens either in the open for example on lawns, or in partial cover for example under bushes.</i>	24 (20.9%)
Domestic building	<i>Badgers found on domestic (rather than farm) property. The places were found varied enormously and included; coal bunkers, garden sheds and a child's Wendy house.</i>	19 (16.5%)
Farm building	<i>Badgers found on farm property in buildings including cattle sheds, feed stores and chicken sheds.</i>	19 (16.5%)
Other	<i>Three animals were found in places which could not be categorised using the headings above, these were one badger found on a beach, and two found in open areas in industrial premises in semi urban areas; a fencing works and an engineering company.</i>	3 (2.6%)

Figure 3.2 Locations in which male and female badgers were found

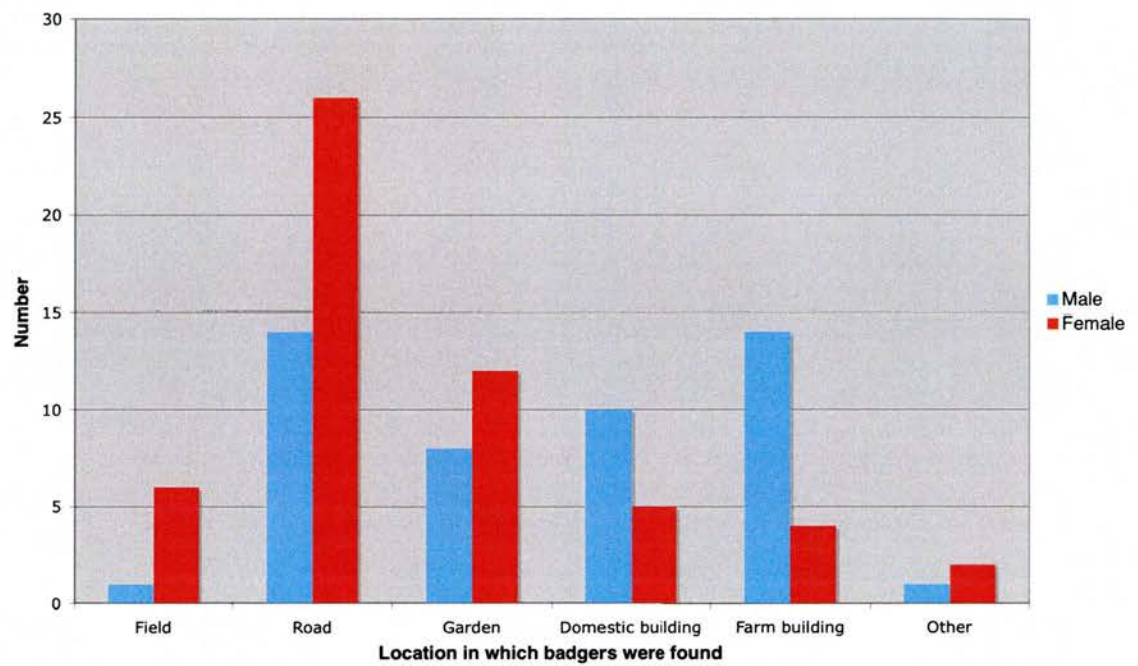
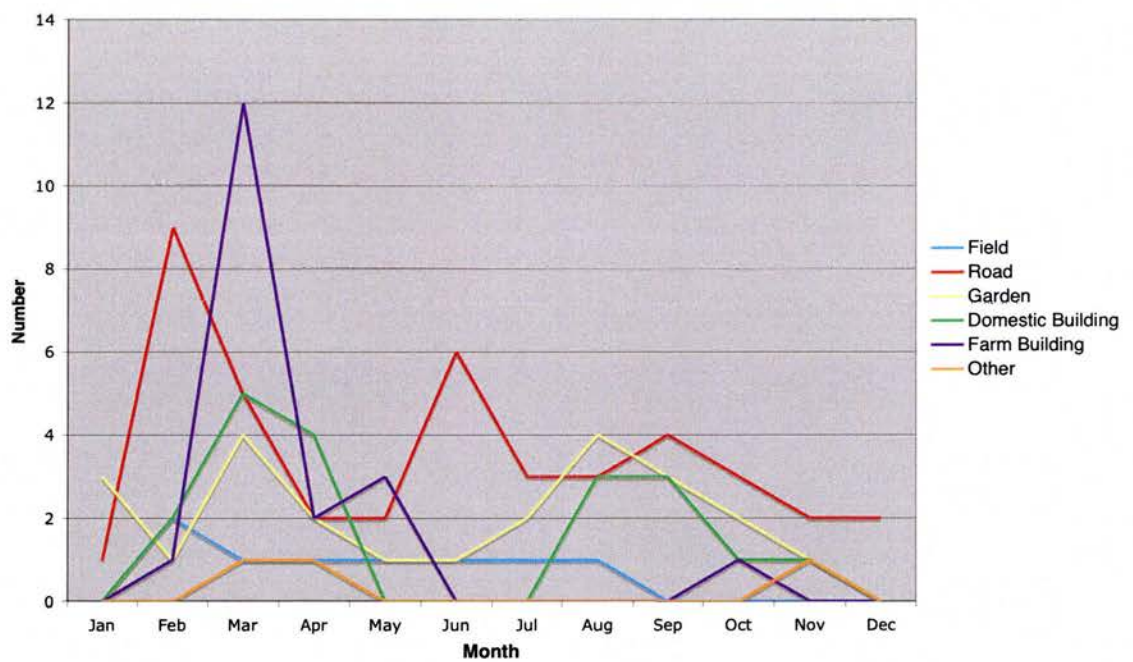


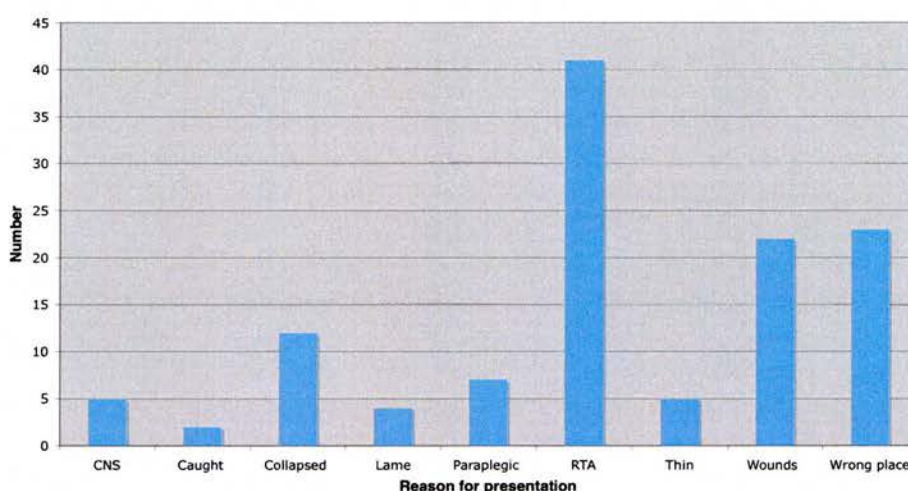
Figure 3.3 Seasonal trends in the location of 115 badger casualties



3.3.3 Finder's reasons from presentation

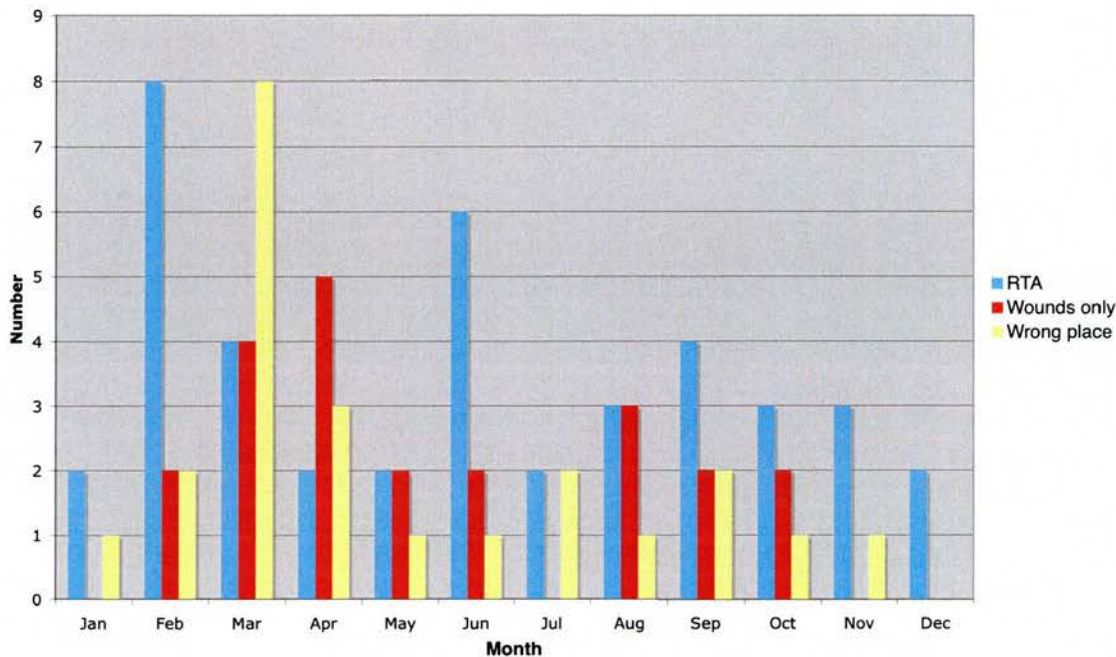
The reason for presentation as described by the finder was recorded in 121 cases and classified into the appropriate category (Table 3.1) as illustrated in Figure 3.4. RTA was the most common reason for presentation of a badger casualty (41 badgers). Of the 23 animals described as being found 'in the wrong place' 8 (35%) were found in gardens, 6 (26%) in domestic buildings and 9 (39%) in farm buildings. Bite wounds (22 cases) were the third most common reason for presentation.

Figure 3.4 Reason for initial presentation of badger casualties as described by the finder



The month of admission was considered for the three most frequently occurring presenting signs; road traffic accidents, badgers with no signs but found in the wrong place and bite wounds only (Figure 3.5). Badgers were significantly more likely to be found 'in the wrong place' in March compared to other months ($P < 0.05$) but there was no significant seasonal occurrence of either RTAs or bite wounds.

Figure 3.5 Month of admission for the three most common reasons for presentation of badgers



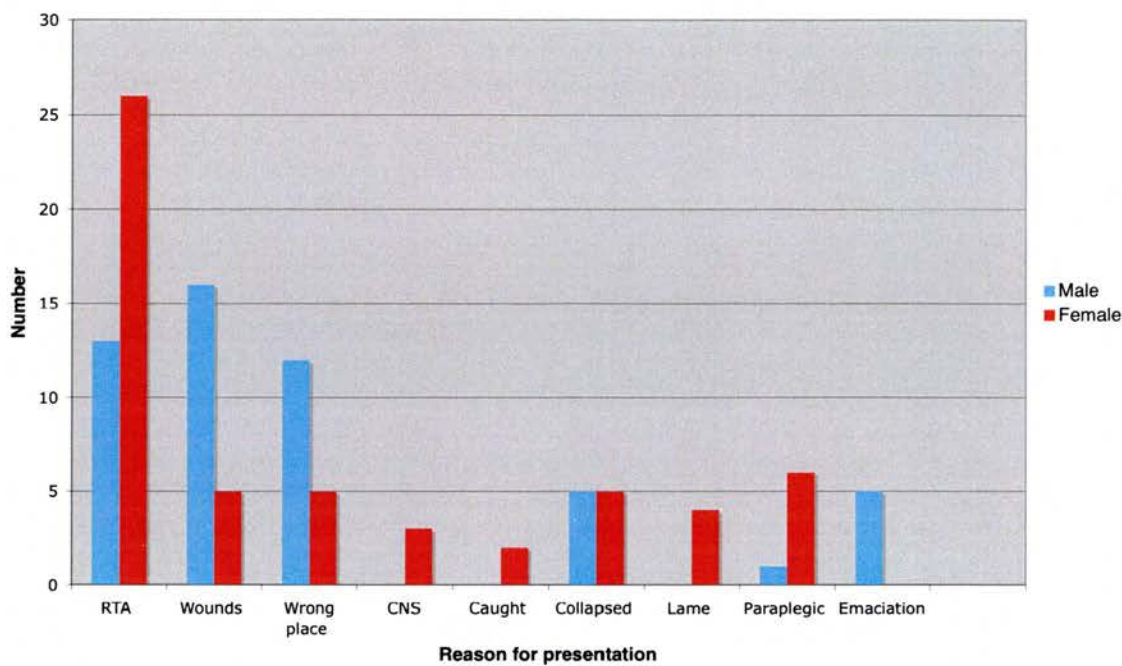
3.3.4 Gender of casualty

Where the sex of the badgers was known (110 cases), there were almost equal numbers of male (54; 49%) and female (56; 51%) badgers admitted.

The reason for presentation as described by the finder is illustrated for male and female badgers in Figure 3.6. Female badgers were significantly ($P < 0.05$) more often involved in RTA than male badgers, 63% versus 32% respectively, whereas wounds were significantly ($P < 0.01$) more common in male badgers, 72.7% versus 22.7% respectively. Badgers found in the wrong place were also significantly ($P < 0.05$) more likely to be male (52%) than female (22%).

Neurological signs, paraplegia and lameness were more common in female badgers but there were too few numbers for statistical analysis. All emaciated badgers were male.

Figure 3.6 Reasons for presentation of male and female badgers



3.3.5 Length and live weight of adult badgers

Five animals were noted as ‘juvenile’ on the record sheets and these data were excluded from further analysis. Range, mean values and standard deviations for length and live weight of 37 male and 44 female adult badgers are presented (Table 3.3).

Table 3.3 Length and live weight of adult badgers

	Range of length (mm)	Mean length (SD)	Range of live weight (Kg)	Mean live weight (SD)
All animals (n=81)	584-985	787 (92)	5.18-15.7	8.35 (2.36)
Males (n=37)	660-985	797 (76)	5.27-13.72	8.03 (2.52)
Females (n=44)	584-970	780 (103)	5.18-15.7	8.59 (2.34)

There was a very large range in the length and weight of male and female badgers. There were no significant gender effects on these parameters.

Mean badger live weight (Kg) was considered in relation to the four quarters of the year (Table 3.4). Contradictory seasonal trends could be seen with lower male bodyweight recordings in the quarters July-September and October-December, while female badgers were heaviest during these quarters. There were no significant differences in the seasonal figures.

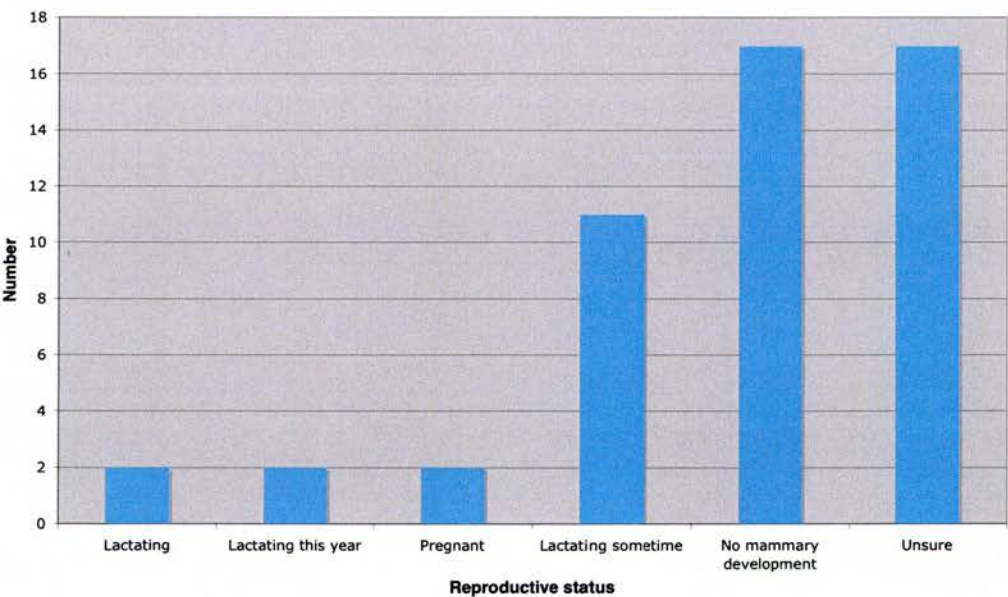
Table 3.4 Mean live weights in adult badgers for each quarter of the year

	Weight (Kg) (SD)		
	Male (<i>n</i> =37)	Female (<i>n</i> =44)	All badgers (<i>n</i> =81)
Jan-Mar	8.3 (2.5)	8.6 (1.86)	8.44 (2.21)
Apr-Jun	8.4 (1.7)	8.2 (3.4)	8.32 (2.68)
Jul-Sep	7.0 (0.9)	8.7 (2.4)	8.15 (2.14)
Oct-Dec	7.4 (2.6)	9.0 (2.5)	8.38 (2.54)

3.3.6 Reproductive status of female animals

The reproductive status of 51 female badgers was recorded (Figure 3.7), in 33% of cases the reproductive status could not accurately be determined.

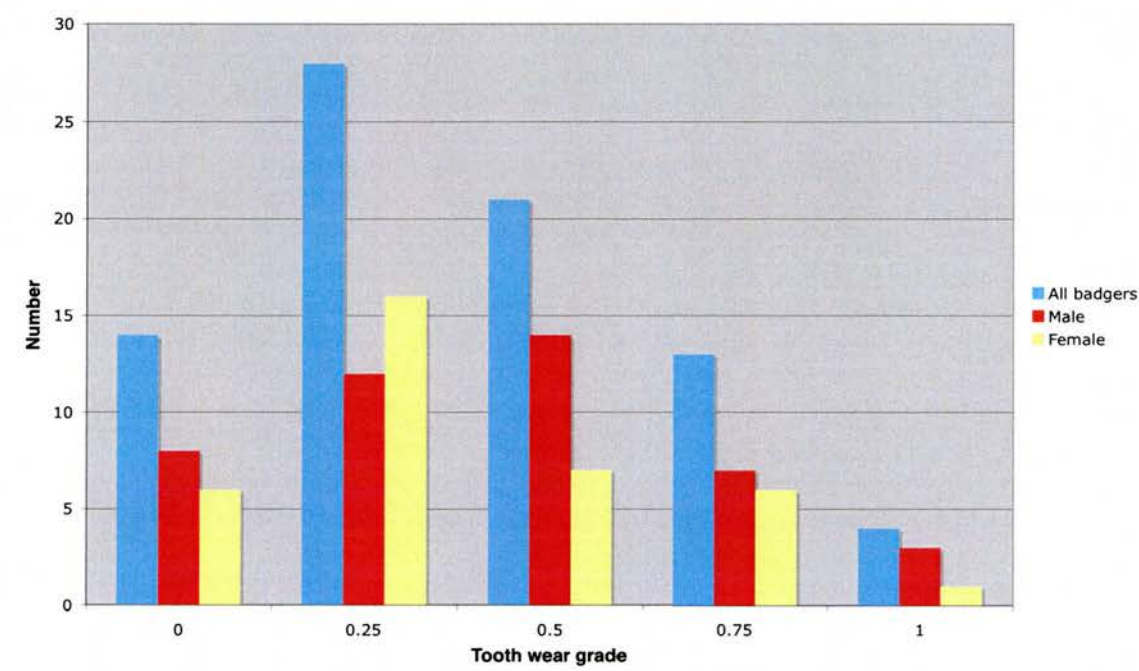
Figure 3.7 Reproductive status of female badgers



3.3.7 Tooth wear grade

The degree of tooth wear was recorded on a five point scale (range 0-1) in 44 male and 36 female badgers (Figure 3.8). Only four badgers showed marked tooth wear. There were no significant differences in tooth wear between the sexes.

Figure 3.8 Tooth wear grades for adult male and female badgers



3.3.8 Badger Trusts and Scottish badgers RTA data

Monthly RTA figures were available from eight English Badger Trust regions, these have been combined, together with figures from Scottish Badgers (Table 3.5). These data are broadly similar to the present study (Figure 3.5), and show the highest numbers of RTAs occurring in February and March.

Table 3.5 Monthly figures for badger casualties based on data from badger groups (Badger Trust and Scottish Badgers)

	Badger Trust regions in England								Total for recorded English counties	Scottish Badgers figures for Scotland
	Dorset	N.E. Essex	Leics.	New Forest	N.Hants	Somerset	Sussex	S.Yorks		
Years recorded	2007-2008	2005-2008	2003-2004	2003-2008	2003-2008	2003-2008	1995-2004	1995-2005	Various	1978-2008
Jan	25	59	14	7	97	1	69	4	276	243
Feb	39	83	36	31	219	10	180	10	608	766
Mar	54	90	20	34	214	4	134	8	558	1121
Apr	22	65	17	37	168	4	85	9	407	875
May	17	59	12	15	163	5	66	8	345	595
Jun	14	56	14	15	113	7	57	7	283	500
Jul	22	48	16	9	103	0	41	9	248	528
Aug	14	41	13	13	68	7	43	4	203	613
Sep	30	56	18	36	89	8	56	6	299	546
Oct	10	41	15	19	86	11	56	5	243	436
Nov	7	21	11	13	48	1	30	3	134	208
Dec	7	11	10	4	37	4	25	1	99	101

3.4 Discussion

The highest numbers of casualties presented to the author’s veterinary hospital and SWWR were in February, March and April, with most casualties in March. A second peak of cases was encountered in August and September. Badgers found at the roadside peaked in February with a second peak in June. Several ecological factors may explain this seasonal distribution. The seasonal ranging behaviour of badgers is inversely related to food availability, which is lowest in the summer months and highest in the autumn (Kruuk and Parish, 1983; Cheeseman *et al.*, 1987; Cresswell *et al.*, 1992; Clifton-Hadley *et al.*, 1993; Delahay *et al.*, 2006a). Patterns of badger emergence from setts follow a diurnal pattern with badgers emerging later in the evening of summer months and earlier in the autumn and winter (Neal and Cheeseman, 1996). The amounts of time spent above ground however show approximately a reverse of this trend with increased time foraging in the summer months and the least activity in the winter (Neal and Cheeseman, 1996). These foraging patterns may explain the high numbers of badger casualties during the summer months, for example as a result of increased ranging resulting in more RTAs, but do not necessarily explain the spring peak in admissions. Reproductive activity in badgers occurs during the early spring after cubs are born and again in the

autumn and results in an increase in territorial disputes and bite wounds (Cresswell *et al.*, 1992). Admissions of casualties with wounds are therefore likely to be higher at these times of year, together with an increase in RTA as territorial boundaries are established. The occurrence of specific problems such as bite wounds and road accidents at certain times of year is discussed further below. A peak in badger visits to farm buildings in England has also been recorded in spring and summer months (Tolhurst *et al.*, 2009) and this, in addition to RTA, may result in an opportunity for increased contact between badgers and man. Studies in hedgehogs have shown seasonal trends with three quarters of admissions to wildlife hospitals occurring between July and December, although this included juveniles (Reeve and Huijser, 1999). Studies in Eurasian otters (*Lutra lutra*) have also shown a seasonal pattern associated with spring and autumn mortality (Simpson, 1997).

There were fewer badger casualties in 2003 than in 2004 or 2005. No reason such as large variations in weather conditions (Met Office, 2010) could be found.

Direct contact with man arising from badgers being found on the road, in domestic gardens and in domestic or farm buildings accounted for the majority of cases admitted. As RTAs are thought to account for the majority of deaths in badgers (Gallagher and Nelson, 1979; Cheeseman *et al.*, 1987; Cheeseman *et al.*, 1988; Neal and Cheeseman, 1996) the number of roadside casualties presented for rehabilitation is not surprising. Road traffic casualties are easily noticed by the general public because roads create an interface between man and badgers and this may bias the reason for submission. Other authors have described such potential bias in epidemiological studies of badgers (Cheeseman *et al.*, 1988) and post-mortem studies of otters (Simpson, 1997). Badgers were found at the roadside after RTA most commonly in February and June. Other authors have reported a similar seasonal association with RTA deaths, with two peaks, in February/March and July (Davis *et al.*, 1987; Neal and Cheeseman, 1996). The information obtained from badger charities in England (Badger Trust) and Scotland (Scottish Badgers) indicated similar seasonal trends with a peak in February in England and March in Scotland. A second smaller peak was seen in August in Scotland and September in England, although this trend was quite variable between the English counties. The differences between

Scotland and England may be attributed to differences in day length and food availability. Data specifically for Somerset for the study period 2003-2006 showed peaks in RTAs in February and October.

In other British mammal species RTAs also account for a high percentage of recorded deaths. In the Eurasian otter the seasonal incidence of RTAs has been shown to relate to the ecology of the species in a way similar to badgers (Simpson, 1997). In urban foxes (*Vulpes vulpes*) it has been suggested that on familiar roads activity patterns of animals are changed and reduce mortality rates (Baker *et al.*, 2007) but such behavioural changes have not been observed in badgers. It is possible that RTA badgers might survive the initial trauma and subsequently be found at other sites, for example after hiding in buildings or gardens, making the true number of RTA cases greater than it may at first appear; the clinical evidence of this is shown in Chapter 4. Equally, it is possible that badgers that are debilitated, for example with tuberculosis, may perhaps more easily succumb to RTA or be found dead at the roadside (L. Corner, *pers. comm.*).

Surprisingly, significantly more female than male badger casualties were found at the roadside; 47% of all female casualties were from this location. RTA was also the main reason for presentation in significantly more females than males. It might have been expected that male badgers would be more likely to be involved in RTA due to increased ranging and territorial behaviour, such as is the case in domestic cats where male animals (neutered and entire) are 1.9 times more likely to be involved in RTAs than females (Rochlitz, 2003). An increased incidence of RTA deaths in male otters has also been described (Simpson, 1997). It may be that RTAs in badgers are less influenced by gender-related territorial behaviour and more by food availability, alternatively male animals may be better physically adapted to avoiding or surviving RTA. Other studies have however, suggested that this is not the case as no statistical difference could be shown between the sexes and RTA deaths (Davis *et al.*, 1987). The clinical impact of RTAs in badgers will be discussed further in Chapter 4.

Badger casualties were found commonly in both domestic and farm buildings. Several other authors have described the use of farm resources, including buildings,

by badgers (Cheeseman and Mallinson, 1981; Sleeman and Mulcahy, 1993; Garnett *et al.*, 2002; Roper *et al.*, 2003; Sleeman *et al.*, 2008; Ward *et al.*, 2008; Tolhurst *et al.*, 2009). The range of farm structures (feed sheds, cattle sheds, silo yards, slurry pits, barns, haystacks, and silage clamps) visited by badgers in search of food has been well documented (Garnett *et al.*, 2002; Roper *et al.*, 2003) and badgers in this study were found in many such places. It has also been suggested that badgers, especially those in extremis, might seek refuge in farm buildings (Cheeseman and Mallinson, 1981) and this may therefore select for debilitated animals that might be admitted for veterinary care. The use of domestic buildings and property by badgers has however, only previously been described in the Moravskoslezské Beskydy Mountains of the Czech Republic where buildings inhabited or visited by badgers included wooden barns, masonry buildings used for residential purposes, abandoned buildings, wooden sheds, wooden beehouses and non-residential parts of houses (Pavlačík, *et al.*, 2004). In this current study a similar range of buildings including sheds, garage and children's play-houses were used by badgers. The Czech study suggested residence of badgers in buildings including sows and cubs, which implies that healthy animals rather than just terminal cases use such facilities. A seasonal use of buildings was also suggested in the Czech Republic, with badgers using the buildings more frequently in winter than in summer (Pavlačík, *et al.*, 2004). Observations suggest the opposite to be true in England, with more frequent use of buildings in the spring and summer when temperatures are higher and rainfall is lower (Garnett *et al.*, 2002; Tolhurst *et al.*, 2009). Such variation may be due to climatic differences between the countries influencing the need for both food and shelter. In the present study however, the seasonal trends appear to be different again, with badgers found in buildings in the spring and autumn. Badgers found in farm buildings peaked in March with 63% of animals from this site presenting during this month. Significantly more male than female animals presented as a result of being 'in the wrong place', usually a building, in March. Such seasonality appears to correlate well with reproductive activity and territorial behaviour, where disputes may be greater in male animals (Cresswell *et al.*, 1992). Male badgers were also significantly more likely to be found in buildings than females, especially in farm buildings. This concurs with other studies where male animals have also been shown

to visit buildings more frequently than female animals (Tolhurst *et al.*, 2008).

Few badgers were found in open fields, which may be due to the animals seeking refuge in their sett or in buildings when injured, or simply that being found by members of the public is less likely when in open countryside. Badgers were found in fields throughout the spring and summer, which either may be an influence of ecological factors such as reproductive trends and food availability, or might simply reflect an increase in people walking in the countryside during these months. The badgers found in fields were predominantly females, possibly illustrating their tendency to remain closer to the sett and their young.

The main reasons for presentation were involvement in a RTA, evidence of wounds, or simply because badgers were in the wrong place, a domestic or farm setting, without other more obvious clinical signs being evident to the finder. Evidence of other disability ('paraplegic' or 'dragging their legs'), debilitation ('thin', 'collapsed' or 'recumbent') were less commonly noted by finders. The main reasons for presentation were not necessarily the only or most significant presenting signs once the badgers were examined further, and do not represent the range of clinical conditions that are discussed more completely in Chapter 4; for example some badgers had bite wounds even though they were presented as 'RTA' or 'in the wrong place', the incidence and clinical significance of such wounds are discussed in Chapters 4 and 5. These data are similar to BWRC figures (2000) that show 39% of all wildlife casualties and 30% of all mammalian casualties present as a result of trauma, whereas only 14% of mammals present as a result of natural causes.

The seasonality of RTAs has been discussed above and as expected, a similar seasonality in those animals presented as known RTA was also seen. Badgers with wounding as the main clinical finding peaked in March and April and again in August which corresponds to peaks in reproductive activity at these times of year (Cresswell *et al.*, 1992). Admissions of wounded badgers over a two-year period to the RSPCA Wildlife Hospital, West Hatch, showed similar seasonality with a peak in admissions in March and the majority of cases seen between February and May (Cousquer, 2002). Bite wounds are discussed further in Chapter 5.

Badgers admitted for rehabilitation were both shorter and lighter than the figures cited in some mammalian texts (Neal, 1977; Delahay *et al.*, 2008). The live weights of the study population were however more akin to those of adult badgers in another study in a high-density population of badgers (Cheeseman *et al.*, 1993). Live weight is dependant upon age, sex, food availability and time of year (Kruuk and Parish, 1983; Clifton-Hadley *et al.*, 1993). The differences in size and live weight in both male and female animals could therefore be attributed to several factors. The study population might include more young badgers that were not fully grown whereas all badgers were said to be over one year old in the published data (Neal, 1977). Every attempt was made to exclude juvenile animals from the study using the criteria described, however those over sixteen weeks may have been included. The study animals came from an area of lower badger density area than that of the Woodchester Park area (Cheeseman *et al.*, 1993) and as such were probably more typical of the general South West area (Delahay *et al.*, 2008). The study population was however biased towards badgers presented during the spring and late summer months when badger live weights would be expected to be lower than normal. The study population might be expected to over-represent smaller, diseased and debilitated badgers that consequently were of a smaller size and lower live weight. Tuberculosis (*M. bovis* infection) has been shown to result in weight loss and emaciation in those animals clinically affected (Clifton-Hadley *et al.*, 1993); other chronic disease conditions would also be expected to have such an effect upon body weight. Clinical influences on live weight and condition are further discussed in Chapter 4 and *M. bovis* infection in Chapter 6.

The live weights of badgers in the study population were considered at different times of year in seasonal quarters. This allowed comparison with mean adult body weights for the same quarters of the year for adult badgers in an undisturbed high-density badger population in Gloucestershire (Cheeseman *et al.*, 1993). The study badgers showed a general trend similar to that observed in other populations, with higher mean live weights in the winter months (October-March) and lower live weights in the summer (April-September). The seasonal weight changes in the Gloucestershire study (Cheeseman *et al.*, 1993) were however, greater in magnitude

and occurred earlier in the year perhaps as a result of the effects of high population density in this area (Rogers *et al.*, 1997a). Badger weights have been shown by others to fall in December (Cresswell *et al.*, 1993) or January (Clifton-Hadley *et al.*, 1993), plateau over the summer months and begin to rise again from September to November (Clifton-Hadley *et al.*, 1993; Cresswell *et al.*, 1993) in response to seasonal variations in food availability (Kruuk and Parish, 1983; Cheeseman *et al.*, 1987; Cresswell *et al.*, 1992; Clifton-Hadley *et al.*, 1993; Delahay *et al.*, 2006a). Weights of badgers increase most as a result of fat deposition before the winter (Cresswell *et al.*, 1992; Zalewski *et al.*, 2007). Body mass has been shown to decline to a greater extent in female animals over the summer months than in males (Clifton-Hadley *et al.*, 1993; Cresswell *et al.*, 1992). There is also a population density effect on body weight that tends to exaggerate the trends normally seen (Rogers *et al.*, 1997a). In this study of clinical cases the mean live weight changes were more dramatic in the male population. This difference might of course be influenced by the small sample size, but may also show that the population of male badgers admitted for rehabilitation in the summer months becomes especially debilitated at this time of year. The clinical aspects of such weight loss are described in Chapter 4.

The sex of adult badger casualty admissions represented the parity found in the natural badger population (Macdonald and Newman, 2002; Dugdale *et al.*, 2003). The natural behaviour of badgers suggests male animals to be more likely casualties than female animals. Changes in the sex ratio occur as the badger population ages. Studies have shown that the overall badger population becomes increasingly female-biased with age (Neal and Cheeseman, 1996; Rogers *et al.*, 1997b), as a result of increased male mortality (Wilkinson *et al.*, 2000). Studies in hedgehogs show more male animals admitted to wildlife hospitals and male animals more likely to be the victims of traumatic injuries as a consequence of increased ranging behaviour (Reeve and Huijser, 1999). Similar findings were observed in male otters (Simpson, 1997), and male domestic cats (Rochlitz, 2003). As described above however, female badgers in this study were significantly more likely to be admitted as a result of RTA than males. Other studies of badgers have shown that males are no more likely than females to be involved in road accidents (Davies *et al.*, 1987; Neal and Cheeseman, 1996), however a female bias towards RTAs has not been suggested previously.

Higher admissions of male badgers from buildings, and as a result of wounding, also concur with other authors (Cresswell *et al.*, 1992; Macdonald *et al.*, 2004b; Delahay *et al.*, 2006b; Tolhurst *et al.*, 2008).

Only six female badgers were considered to be sexually active; either pregnant, lactating recently, or lactated this year. Female badgers during late pregnancy and the first 6-8 weeks of lactation would be unlikely to come into care as they are unlikely to venture far from their sett (Neal and Cheeseman, 1996). Pregnant animals and sows with cubs have been reported nesting in farm buildings and piles of vegetation above ground in England (Neal and Cheeseman, 1996) and sows with cubs have been reported in buildings in the Czech republic (Pavlacík, *et al.*, 2004). This clinical study included a sow and cub that were found in a hay barn. Territorial disputes in female animals have also been shown to peak in the postpartum period (Cresswell *et al.*, 1992) and this may result in lactating animals being presented for veterinary care.

Reproductive losses may occur at three stages; failure to conceive, failure to implant, and failure of cubs to survive to emergence from the sett (Cresswell, *et al.*, 1992). These reasons may explain the low numbers of badgers that were found to be lactating in this study. Although differentiation between 'lactating sometime' and 'never lactating' has been made by other researchers (R. Delahay *pers. comm.*), such differentiation was difficult with many assessments being classed as 'uncertain' and consequently no conclusions could be drawn from these data.

Several methods of aging badgers have been considered (Hancox 1988b; Harris *et al.*, 1992; Delahay *et al.*, 2008), including morphological studies of annuli in sectioned teeth (Ahnlund, 1976; Ahnlund, 1980), the degree of epiphyseal closure in animals under 18 months old (Ahnlund, 1976; Hancox 1988b; Cresswell *et al.*, 1992) and molar tooth wear (Hancox, 1988c; Harris *et al.*, 1992). The use of tooth annuli has been found to be an especially poor method of ageing badgers in the south west of England (Ahnlund, 1980).

Epiphyseal closure could have been assessed in this study using radiography (Page, 1994) but as juvenile animals were largely excluded from the study such techniques were not employed. Some debate exists over the use of tooth wear for age

assessment (Hancox, 1988; da Silva and Macdonald, 1989) but when compared to reference material of badger skulls of known age has been shown to be reasonably accurate, with 74% of animals correctly aged and 98% within one year (Cresswell *et al.*, 1992; Harris *et al.*, 1992). Molar wear was however found to be a more accurate estimation of age in younger animals up to three years old (Cresswell *et al.*, 1992; Harris *et al.*, 1992). In other studies the classification of animals as 'cub' (with temporary dentition), 'yearling' (with unworn adult dentition) and 'animals in their third year or older' (where there is molar wear) have been considered adequate for field research (Cresswell *et al.*, 1992; Harris *et al.*, 1992). The Woodchester Park classifications used in this study assume that 25% molar wear (0.25 classification) does not occur until animals are in their second year. The results of the tooth wear studies suggested that 18% of badgers admitted were less than two years old. The range of tooth wear results also indicated that badgers across a range of ages were admitted for veterinary care rather than just very old animals as might perhaps have been postulated. Most adult badgers do not live over six years in the wild (Neal and Cheeseman, 1996; Delahay *et al.*, 2008) although exceptional wild animals and captive animals may live well into their teens (Neal and Cheeseman, 1996; P. Kidner, *pers. comm.*).

The age distribution of the badger population is dependent upon the mortality rate at different ages. High mortality rates in cubs have been observed with 50-65% of deaths occurring within the first year (Cheeseman *et al.*, 1987; Cresswell *et al.*, 1996; Neal and Cheeseman, 1996). Annual mortality rates of 30% for males and 24% for females have been reported (Neal and Cheeseman, 1996; Wilkinson *et al.*, 2000) resulting in the badger population becoming increasingly female with age (Neal and Cheeseman, 1996; Rogers *et al.*, 1997b). Female and male animals in the study group were equally represented in the '0' tooth wear category, but overall females had generally lower tooth wear grades than males. This might suggest that younger female animals are over represented in casualty admissions despite the natural female bias of the badger population with age. However, interpretation of such data without the use of reference material of known age is limited and the tooth wear grades might simply be a reflection of environmental or dietary factors in female animals rather than their increased age.

3.5 Summary

Seasonal trends in veterinary admissions of adult badger casualties were consistent with known ecological factors such as seasonal activity, food availability, and reproductive behaviour. The ecology of this species is also a major factor in determining how they are found by members of the general public and presented for veterinary treatment. Ranging and foraging behaviour brings badgers into contact with humans at the roadside. Badgers seek refuge after traumatic incidents or territorial disputes in both farm and domestic premises, and in order to make use of farm resources. Badgers found in buildings may be genuinely in need of veterinary assistance or may simply be viewed as pest animals being in the wrong place. Most veterinary cases were presented as a result of some form of obvious trauma evident to the finder. Bite wounds as a result of territorial disputes with other badgers were one common reason for presentation.

Badgers in this study were smaller and of lower live weight than animals in other wild populations. This is most likely a reflection of the time of year animals are admitted to veterinary practices as well as the effects of chronic disease. Males and females were equally represented in the study population. Female animals however, were more frequently found at the roadside and male animals were found more often in buildings, especially farm buildings. Few female badgers were either pregnant or lactating. Tooth wear scores suggest badgers of all ages are presented for veterinary care.

The findings of this veterinary practice-based clinical study have informed and educated veterinarians and rehabilitators of the types of badger casualties that are likely to be presented at each time of year. The seasonal occurrence of certain problems may assist with planning staffing rotas and resources. The high incidence of contact of badgers with man at the roadside and in buildings may be useful to road planners and housing developers. The zoonotic significance of close contact between humans and badgers potentially infected with *Mycobacterium bovis* is discussed in Chapter 6.

Chapter 4

Clinical findings

4.1 Introduction

Research into disease and causes of mortality in badgers has been much greater than for other wildlife species since the implication of badgers in the transmission of bTB to cattle in 1971 (Muirhead *et al.*, 1974). Most research however relates to epidemiology and post-mortem findings associated with bTB and is of limited interest to the veterinarian in general practice. Gallagher and Nelson (1979) described diseases in badgers during a post-mortem survey and found RTAs, tuberculosis and the effects of bite wounds the most significant causes of death, and clinical signs of these conditions would therefore be expected to be seen in badgers presented to veterinary practices. Published work relating to the clinical treatment of badgers is limited to inclusion of the species in triage discussions and species-specific chapters in textbooks (Best and Mullineaux, 2003; Mullineaux, 2003a; Gosden, 2004; Stocker, 2005), together with short published papers specifically related to badgers (Lewis, 1997b, c; Keeble, 1999; Cousquer, 2002; Cousquer, 2005).

RTAs are considered the major cause of mortality in badgers (Gallagher and Nelson, 1979; Cheeseman *et al.*, 1987; Cheeseman *et al.*, 1988) even in those populations with endemic tuberculosis (Gallagher and Nelson, 1979; Cheeseman *et al.*, 1988; Clifton-Hadley *et al.*, 1993). Some aspects of the management of RTA injuries have been considered in veterinary publications (Lewis, 1997b, c; Mullineaux, 2003a; Cousquer, 2005; Stocker, 2005) although the true clinical significance of RTA in casualty badgers has not fully been investigated.

Tuberculosis is considered the most important disease affecting badgers in Britain but the mortality rate is low (Cheeseman *et al.*, 1989). The main post-mortem findings are 'poor body condition' and 'emaciation' (Clifton-Hadley *et al.*, 1993) which may be difficult to differentiate from other causes of weight loss. Seasonal variations in badger weight (Kruuk and Parish, 1983; Cheeseman *et al.*, 1987; Cresswell *et al.*, 1992; Clifton-Hadley *et al.*, 1993; Delahay *et al.*, 2006a) may further confuse the interpretation of these non-specific findings. The clinical impact of tuberculosis and its importance in badgers presented to veterinarians in general practice is currently unknown.

Bite wounds arising from conspecific territorial disputes have been described in badgers presented to veterinary surgeons and several methods of treatment have been suggested (Keeble, 1999; Cousquer, 2002; Mullineaux, 2003). The incidence of bite wounds in casualty badgers and their clinical significance in the assessment and treatment of these animals is limited. Other clinical conditions such as dental disease, and trauma as a result of snares, have also been described (Lewis, 1997c; Mullineaux, 2003a) but their true significance remains unknown.

In this chapter the clinical reasons for presentation of badger casualties are investigated. This information will be useful in making clinical triage decisions regarding badger casualties in the future and consequently prevent unnecessary suffering and protracted times in captivity. Such clinical information is also useful for the education of other veterinary professionals.

4.2 Materials and Methods

Records were completed for the 123 badger casualties as previously described (Chapter 2). Once clinically stable and considered fit for sedation (2.4) badgers were fully examined. Examination included an assessment of body condition (Appendix 1.1.3), completion of a dental chart (Appendix 1.1.5) and assessment of tooth wear (Appendix 1.1.6). Bite wounds were recorded as being present or absent and classified according to body position, number, chronicity and size (Appendix 1.1.7).

A full veterinary clinical examination was carried out under sedation. At the start of the study blood samples were collected and radiographs taken only as clinically required and financially possible (2.5). From February 2004 radiography (57 badgers), biochemistry (50 badgers) and haematology (29 badgers) were performed on as many casualties as was practicable. Biochemical tests and radiographs were processed immediately in house allowing interpretation as part of the overall assessment. Haematological results were usually returned within 24hrs from the external laboratory.

Biochemical and haematological tests were interpreted by comparison with normal canine values and published badger values (Appendix 2.6). *M. bovis* serology was intentionally carried out retrospectively in order to follow the badger rehabilitation policy adopted (SWWR *et al.*, 2003). Clinical triage principles were applied throughout the initial assessment and examination (2.3). Badgers either received appropriate clinical treatment (2.6) or were euthanased for welfare reasons.

Clinical summary sheets (Appendix 1.4) were completed to include clinical examination, blood results and radiographic findings, with a summation of the clinical findings. Radiographic interpretation sheets (Appendix 1.5) were used to group radiographic findings according to site and type of lesion. The major clinical finding in each case was classified into one of six categories; none present, acute or chronic trauma, acute or chronic disease, or bite wounds, as summarised in Table 4.1.

Table 4.1: Classification of the major clinical finding in adult badger casualties

Clinical findings	Examples
None	Appears clinically normal.
Acute trauma	Evidence of recent RTA, fresh injuries, blood results indicative of significant recent haemorrhage.
Chronic trauma	Radiographic evidence of healing or healed fractures.
Acute disease	Appears well, good condition but seizure activity or vomiting.
Chronic disease	Thin, blood samples show abnormalities consistent with chronic disease.
Bite wounds only	Bite wounds but no other clinical problems identified.

The major body system affected in each case was classified as shown in Table 4.2. All classifications were based on the most clinically significant findings likely to have brought the badger into captivity. Bite wounds were not considered to be a primary cause of debility or disease unless they were the only clinical abnormality found. Bite wounds were classified separately from other cutaneous diseases or trauma.

Table 4.2: Classification of body systems in adult badger casualties

None
Cutaneous (not bite wounds)
Musculoskeletal
Neurological (CNS or peripheral nerves)
Cardiopulmonary
Renal / urinary
Gastrointestinal
Systemic / multisystem trauma or disease
Bite wounds only

4.3 Results

4.3.1 Body condition

The body condition was recorded for 112 out of the 123 cases; in 104 badgers the sex was also recorded (Figure 4.1). There was no significant difference between the body condition scores recorded for male and female animals.

Body condition was considered for animals presented in the four quarters of the year as shown for all animals, males and females in Figures 4.2, 4.3 and 4.4, respectively. The seasonal mean weight of adult badgers in the study is presented in Table 3.13. There was no seasonal difference in the body condition score of the whole study population in the four seasonal quarters ($P > 0.05$). Male badgers were more frequently in poor condition from January to March than at other times of year but this difference was not significant. Female badgers were significantly more likely to be in poor condition from July to September ($P < 0.01$) than during other quarters, and in good condition between January and March ($P < 0.05$).

Figure 4.1 Body condition of 112 adult badger casualties

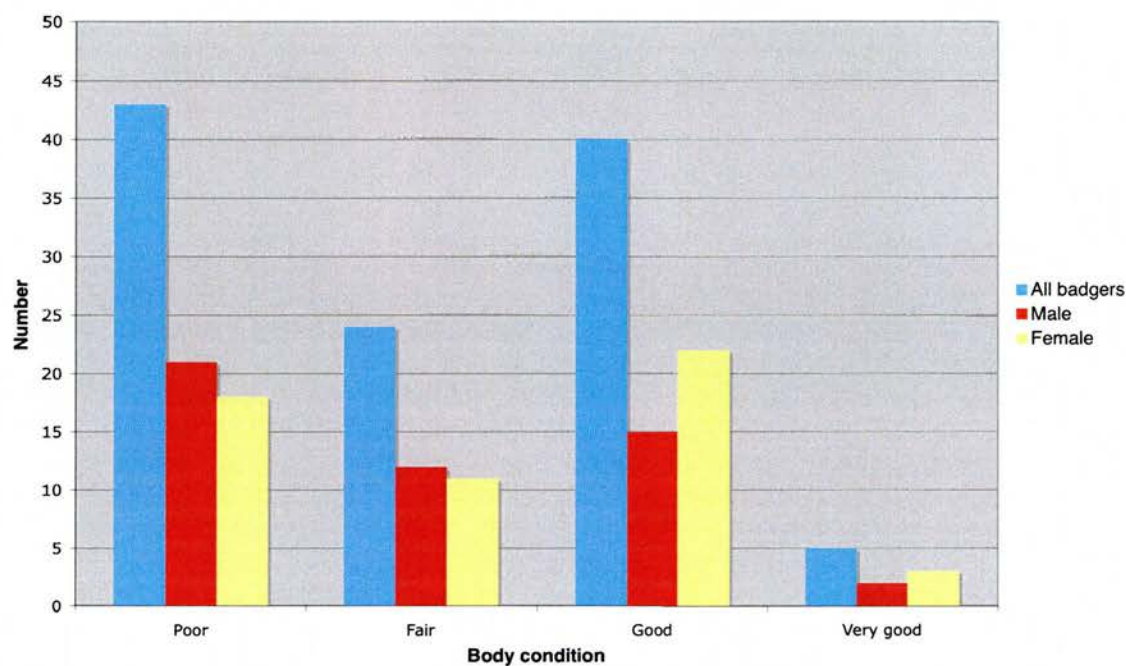


Figure 4.2 Body condition in adult badgers in each seasonal quarter of the year

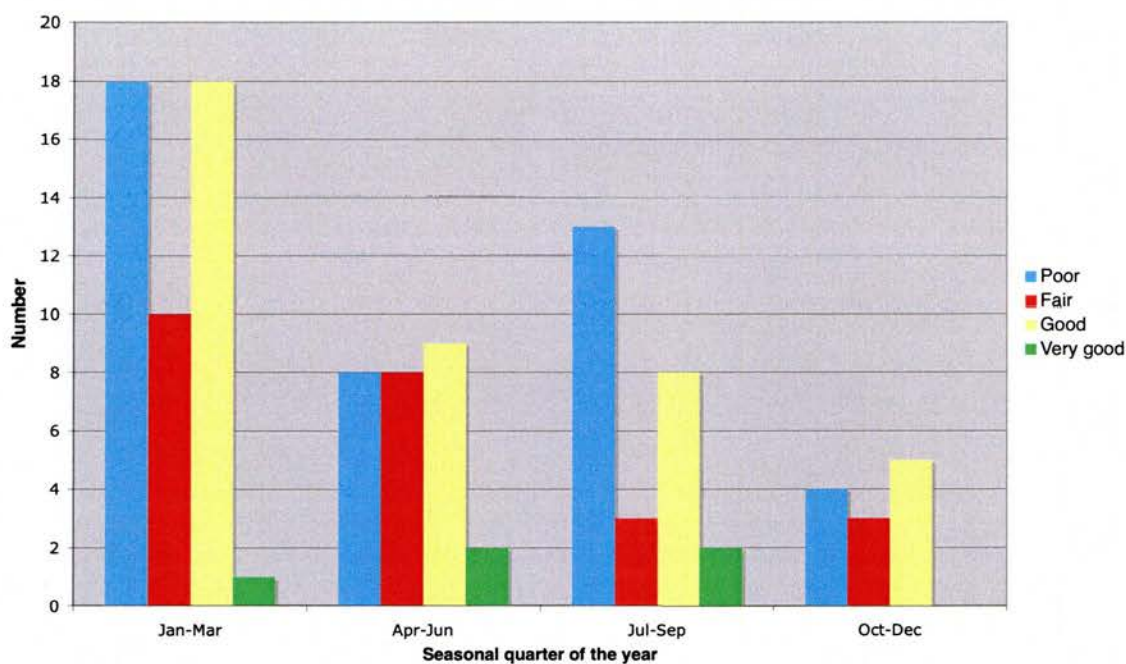


Figure 4.3 Body condition in male badgers in each seasonal quarter of the year

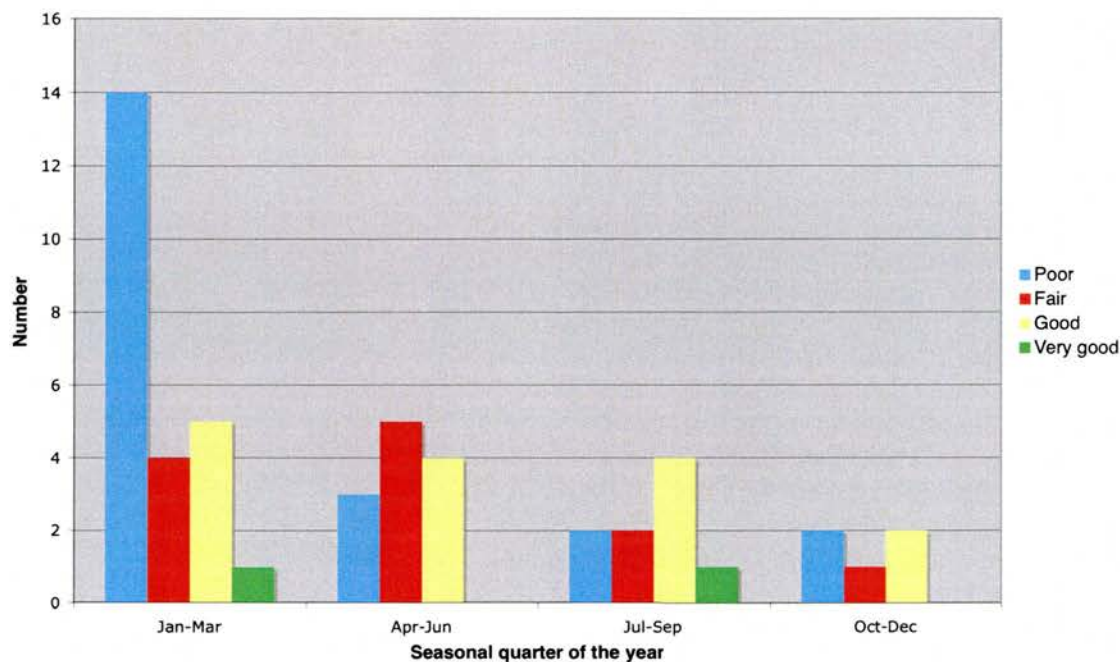
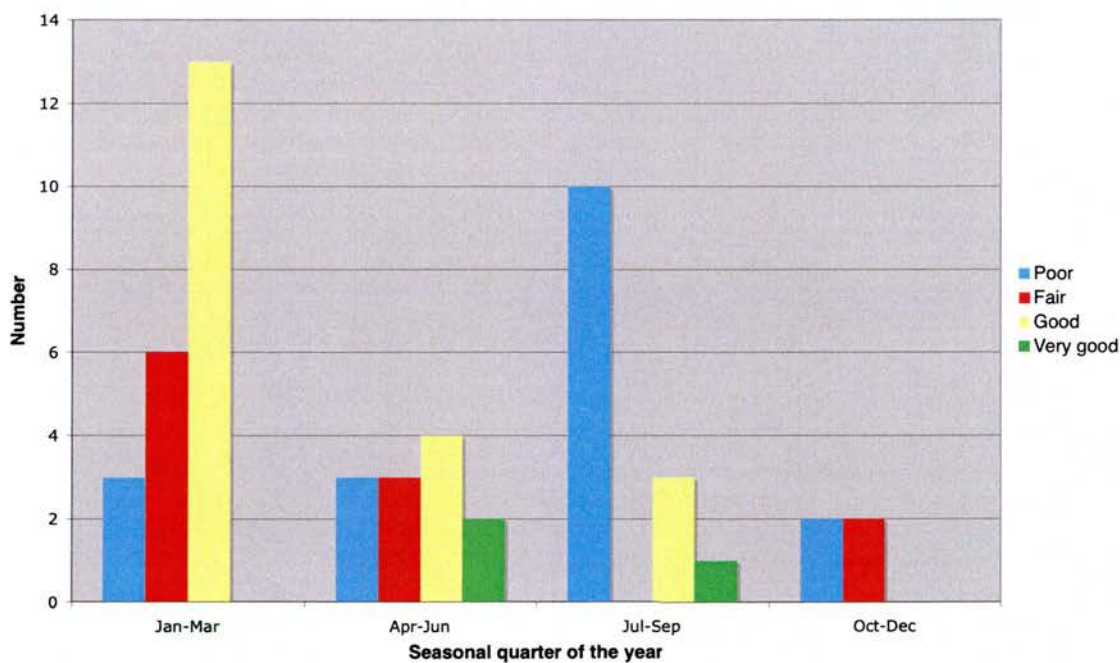
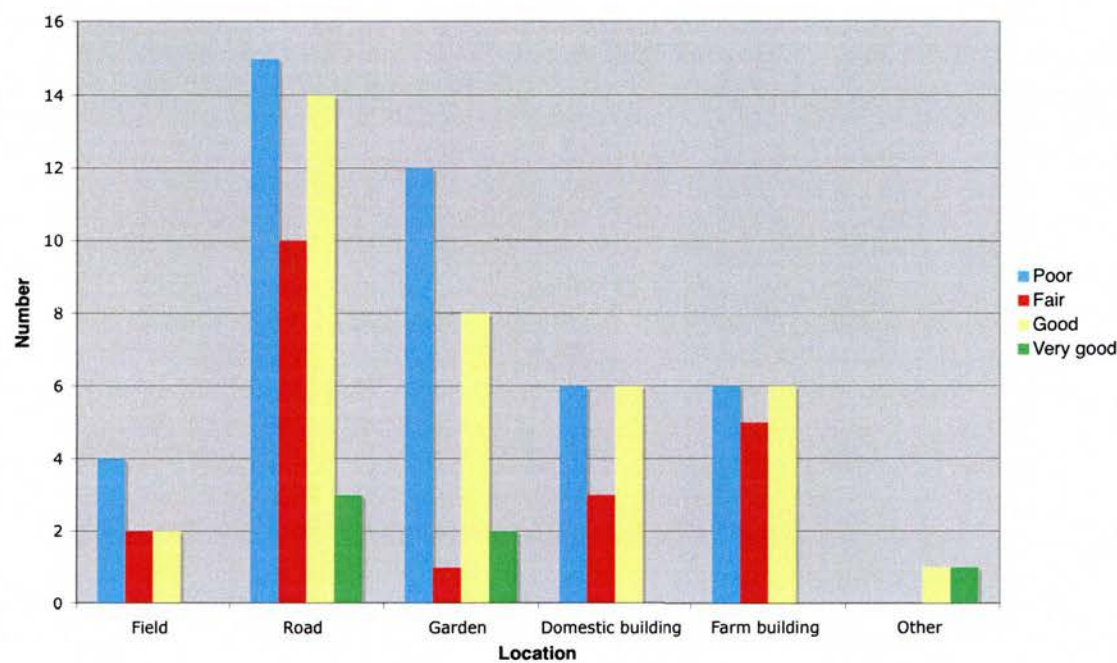


Figure 4.4 Body condition in female badgers in each seasonal quarter of the year



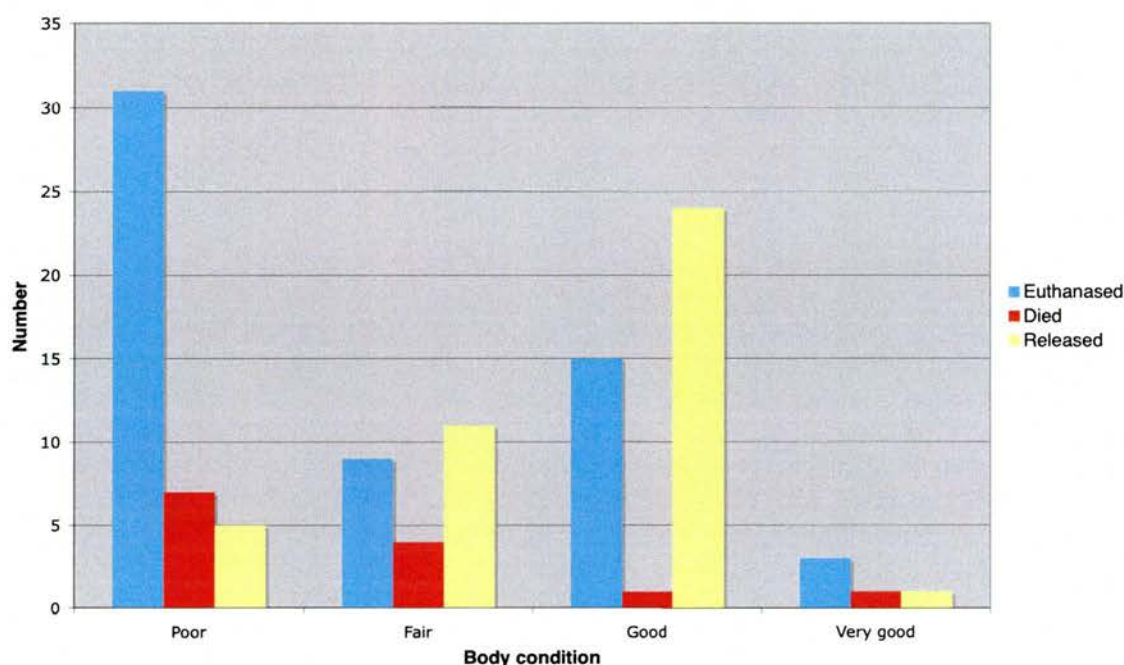
Body condition was also considered in relation to the location in which the animal had been found (Figure 4.5). There was no significant difference in the body conditions of badgers found in the different locations.

Figure 4.5 Body condition in adult badgers according to the location in which they were found



Body condition was considered in relation to the final outcome for the badgers; released, euthanased or died. There was a significant correlation between body condition and outcome; badgers in poor condition were significantly less likely to be released ($P < 0.001$) and significantly more likely to be euthanased ($P < 0.001$), whilst those in good condition ($P < 0.001$) were significantly more likely to be released. (Figure 4.6).

Figure 4.6 Body condition of adult badgers in relation to final outcome



4.3.2 Dental disease

Dental charts were completed in 81 cases, with fractured and missing teeth the more common abnormalities (Figure 4.7). There were no significant differences in the prevalence of dental abnormalities between the sexes.

36 badgers had fractured teeth; canine teeth were fractured in 31 cases (86%), incisor teeth in 5 cases (14%) and both canine and incisor teeth in 8 cases (22%). Pre-molars and molars were frequently worn but never fractured. 29 badgers had missing teeth; incisor teeth were most frequently missing in 23 (79%) of cases, canine and pre-molar teeth were missing in 7 cases (24%) each. Only one animal had a missing molar tooth. Two casualties had to have teeth removed, a canine tooth in one case and several incisors in another, because these teeth had been irreparably avulsed during traumatic injuries.

No significant difference in badger body condition could be attributed to dental abnormalities found in the present study (Figure 4.8).

Figure 4.7 Summary of dental findings in 81 badgers

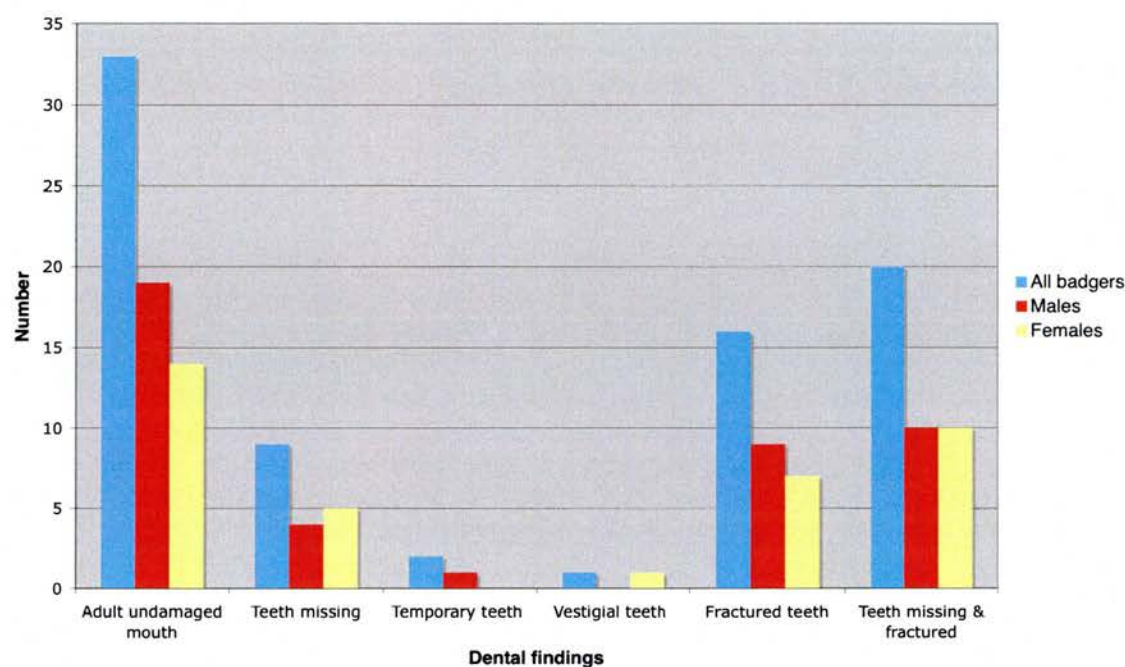
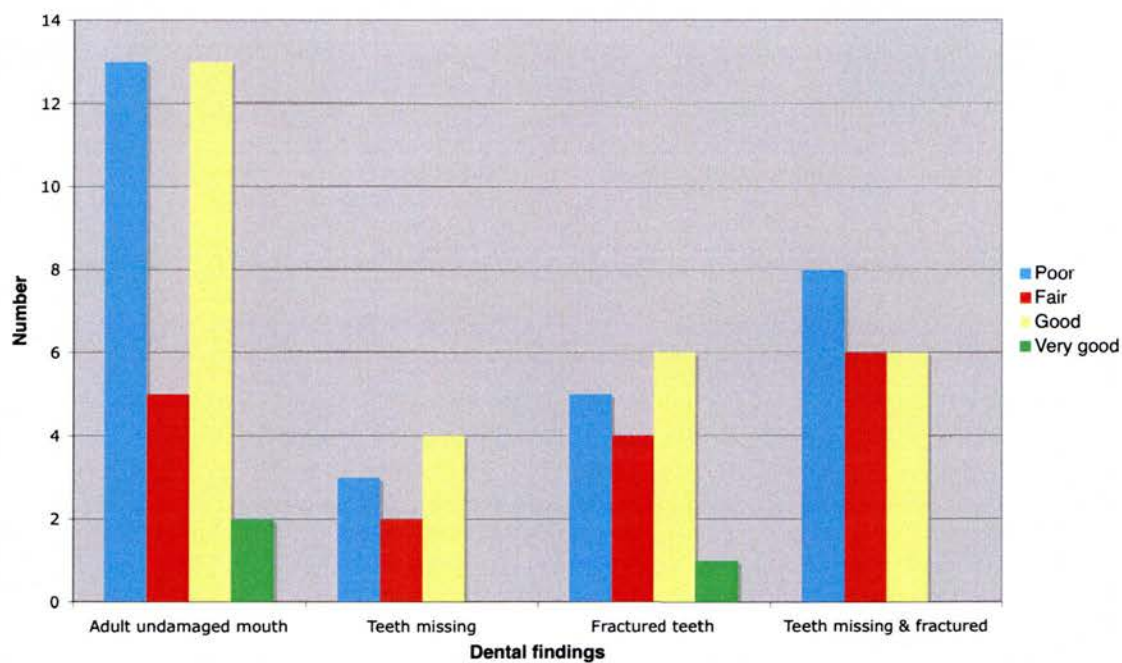
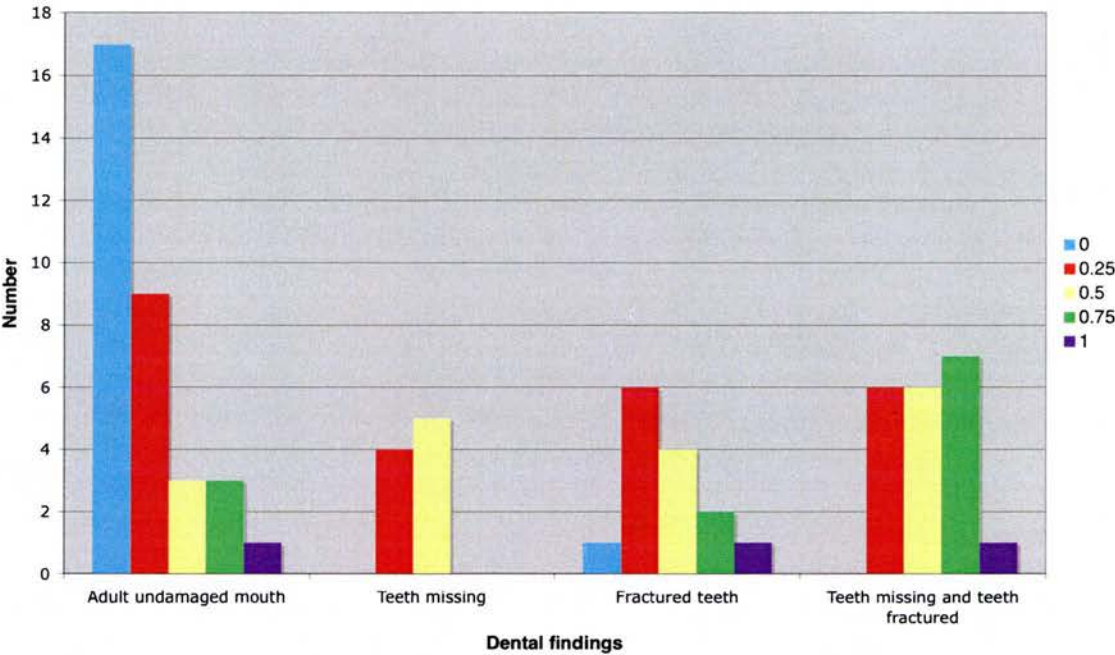


Figure 4.8 Body condition in badgers with normal adult dentition and with dental abnormalities



Tooth wear grades had been recorded as an indicator of age as described in Chapter 3 and shown in Figure 3.8. Tooth wear grades were compared to other dental characteristics as shown in Figure 4.9. As would be expected, there were significantly fewer dental abnormalities ($P < 0.001$) in those animals with tooth wear grade 0, but no significant differences between the other tooth wear grades.

Figure 4.9 Tooth wear grades (0-1) compared to other dental findings in adult badgers



4.3.3 Bite wounds

The demographics of bite wounds in the study population have been discussed in Chapter 3. Bite wounds were the reason for presentation in 22/121 (18%) cases (Figure 3.4). On clinical examination however, the true prevalence of badgers with bite wounds was 76/121 (55%). Since bite wounds were such a frequent finding their clinical significance and impact upon outcome is discussed separately in Chapter 5.

4.3.4 Blood results

Blood values for the study badgers in the period from February 2004 were compared with laboratory reference intervals for dogs and published badger ranges (Appendix 2.6). Few badgers had biochemical values, haematological parameters and electrolyte

concentrations within standard reference intervals or ranges (Table 4.3). Animals that had previously been described as juvenile were excluded from these data.

Table 4.3 Number of study badgers with blood values within canine (Idexx laboratories) and badger (Mullineaux, 2003a) reference ranges

	Canine reference intervals			Badger ranges	
	Biochem. (n=50)	Haematol. (n=29)	Electrolytes (n=43)	Biochem. (n=50)	Haematol. (n=29)
Badgers tested with values within reference ranges	0	0	21	0	5
Badgers tested with values outside reference ranges	50	29	22	50	24

It was not possible to compare the demographics of ‘normal’ and ‘abnormal’ animals because most badgers had blood values outwith standard ranges. The clinical significance of the ‘abnormal’ blood results should be challenged, especially where ranges are based upon small populations from a single site.

The blood results for individual badgers were interpreted alongside the animal’s history and clinical findings (4.3.6) including radiography (4.3.5) where appropriate. The badgers were then divided into the six clinical categories: no clinical findings, acute trauma, chronic trauma, acute disease, chronic disease and bite wounds only (4.2.2, Table 4.1). There were no badgers sampled that were clinically normal.

4.3.4.1 Plasma amylase

Plasma amylase concentrations were measured for 49 badgers with a range of 220-686U/l and a mean value of 335U/l (+/- 100U/l), 45 badgers (92%) had values below the canine reference interval (500-1500U/l). No badger reference ranges are available.

4.3.4.2 Plasma glucose

Plasma glucose concentrations were measured for 49 badgers with a range of 0.4-22.9mmol/l and a mean of 7.2mmol/l (+/- 3.8mmol/l). The canine reference interval is 4.1-7.9mmol/l.

4.3.4.3 Plasma urea and creatinine

Plasma urea and creatinine concentrations, and urea/creatinine ratios were determined for 50 badgers in the six clinical categories (Table 4.4). Canine reference intervals for plasma urea and creatinine concentration are 2.9-5.6mmol/l and 44-195µmol/l respectively and badger ranges 2.9-11.2mmol/l and 68.4-121.1µmol/l. In dogs the reference urea (mmol/l)/creatinine (µmol/l) ratio is <0.08 (Bush, 1991). There was no significant difference in plasma urea and creatinine concentrations between the acute trauma, chronic disease and bite wound groupings because of the large range of values giving large standard deviation figures. Too few badgers suffered chronic trauma and acute disease for meaningful statistical analysis.

Table 4.4 Plasma urea and creatinine concentrations for 50 badgers in five clinical groupings

Clinical finding	Urea (mmol/l)			Creatinine (µmol/l)			Urea/creatinine ratio		
	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD
Acute trauma (n=18)	6.03-46.41	14.76	13.18	10-159	50.67	41.15	0.11-1.23	0.35	0.29
Chronic trauma (n=5)	2.9-12.19	7.58	3.30	43-124	67.8	33.14	0.06-0.19	0.12	0.05
Acute disease (n=2)	3-14.5	-	-	47-63	-	-	0.05-0.31	-	-
Chronic disease (n=11)	5.0-33.87	12.74	8.08	23-62	36.3	11.7	0.14-1.12	0.39	0.29
Bite wounds (n=14)	4.9-46.4	13.33	10.86	20-63	44.14	15.85	0.1-0.41	0.36	0.35
All badgers sampled (n=50)	3.0-46.41	12.95	10.59	20-159	47.57	29.22	0.05-1.41	0.33	0.29

4.3.4.4 Plasma protein concentrations.

Plasma albumin and globulin concentrations were considered, together with albumin/globulin ratios for 49 badgers in the six clinical categories (Table 4.5). Canine reference intervals and badger reference ranges are 23-40g/l and 30.8-42.3g/l for albumin, and 25-45g/l and 21.1-34.5g/l for globulin, respectively. The reference albumin/globulin ratio for dogs is 0.5-1.3 (Bush, 1991).

20 (41%) of badgers tested had albumin concentrations below the canine range and 25 (51%) had globulin concentrations above the canine range, 25 (51%) animals had albumin/globulin ratios below 0.5.

Badgers with chronic disease had lower plasma albumin concentrations than those badgers with acute trauma although this finding was not statistically significant. There were too few badgers with chronic trauma for meaningful statistical analysis.

The albumin/globulin ratio was lower in the bite wound category compared to the acute trauma group but again this finding was not statistically significant.

Table 4.5 Plasma protein concentrations in 49 badgers in five clinical groupings

Clinical finding	Albumin (g/l)			Globulin (g/l)			Albumin/globulin		
	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD
Acute trauma (n=18)	15-29	24.4	4.1	39-60	46.4	5.9	0.42-0.67	0.53	0.12
Chronic trauma (n=5)	24-29	26.6	2.1	44-59	53.4	6.0	0.44-0.61	0.5	0.06
Acute disease (n=2)	20-26	-	-	36-54	-	-	0.48-0.56	-	-
Chronic disease (n=11)	10-25	19.1	4.9	36-68	49.5	9.0	0.22-0.48	0.39	0.08
Bite wounds only (n=13)	20-31	22.92	4.5	43-56	50.0	3.7	0.33-0.65	0.46	0.09
All badgers sampled (n=49)	10-31	23.0	4.8	36-68	48.7	6.7	0.22-0.67	0.48	0.10

4.3.4.5 Plasma calcium concentrations

Plasma calcium concentrations were adjusted for albumin as described in Appendix 2.4 and reported for 48 badgers in the five clinical categories (Table 4.6). Canine reference intervals for calcium are 1.98-3.00mmol/l. A range of 2.01-2.54 has been reported in badgers. There was no significant difference in plasma calcium concentration between the disease categories.

Table 4.6 Plasma calcium concentrations in 48 badgers in five clinical groupings

Clinical finding	Calcium (mmol/l) adjusted for serum albumin (g/l)		
	Range	Mean	SD
Acute trauma (n=18)	2.07-2.61	2.41	0.15
Chronic trauma (n=5)	2.27-2.83	2.57	0.21
Acute disease (n=2)	2.32-2.75	-	-
Chronic disease (n=11)	2.33-2.66	2.42	0.10
Bite wounds only (n=12)	2.02-2.6	2.42	0.16
All badgers sampled (n=48)	2.02-2.83	2.43	0.15

4.3.4.6 Red cell counts

Red blood cell count ranges of $5.5\text{--}8.5 \times 10^{12}/\text{l}$ and $6.93\text{--}12.99 \times 10^{12}/\text{l}$ have been suggested in dogs and badgers, respectively. Lower mean red blood cell counts were observed in badgers with bite wounds and chronic disease (Table 4.7), although these differences were not significant as a result of the the small sample size.

Table 4.7 Red cell counts in 29 badgers in five clinical groupings

Clinical finding	Red blood cell count ($\times 10^{12}/\text{l}$)		
	Range	Mean	SD
Acute trauma ($n=9$)	7.0-12.29	7.84	3.16
Long-standing trauma ($n=4$)	7.08-9.88	7.99	1.30
Acute disease ($n=1$)	10.31	-	-
Chronic disease ($n=9$)	3.19-9.91	6.24	2.14
Bite wounds only ($n=6$)	4.13-7.85	6.26	1.69
All badgers sampled ($n=29$)	3.06-12.29	7.12	2.43

4.3.4.7 White cell counts

Total white cell counts of $6.0\text{--}15.0 \times 10^9/\text{l}$ and $2.6\text{--}10.4 \times 10^9/\text{l}$ have been suggested in dogs and badgers, respectively. Slightly higher mean white blood cell counts were reported in badgers suffering from acute trauma (Table 4.8) but this difference was not significant.

Table 4.8 Total white cell counts in 29 badgers in five clinical groupings

Clinical finding	Total white blood cells ($\times 10^9/\text{l}$)		
	Range	Mean	SD
Acute trauma ($n=9$)	4.5-16.3	10.11	4.29
Long-standing trauma ($n=4$)	5.0-20.2	9.15	7.37
Acute disease ($n=1$)	10.1	-	-
Chronic disease ($n=9$)	3.0-16.4	8.73	3.78
Bite wounds only ($n=6$)	4.8-19.2	8.85	5.49
All badgers sampled ($n=29$)	3.0-20.2	9.29	4.57

4.3.5 Radiographic findings

Radiographic abnormalities were detected in 35 of 57 badgers (61%); 13 badgers (23%) had two or more radiographic abnormalities. Abnormal radiographic findings were classified according to the type of abnormality and the body part (Appendix 1.5) with results summarized in Table 4.9.

Table 4.9 Classification of radiographic abnormalities in 35 badgers according to affected body parts

Body part	Radiographic abnormality					
	Fracture	Dislocation	Bone lysis / proliferation	Abnormal soft tissue density	Abnormal soft tissue lucency	Rupture
Skull	0	0	0	-	-	-
Spine	0	2	1	-	-	-
Ribs	0	0	0	-	-	-
Forelimb	6	1	7	-	-	-
Pelvis	8	1	2	-	-	-
Hindlimb	4	1	10	-	-	-
Abdomen	-	-	-	2	2	2
Thorax	-	-	-	6	2	1
TOTAL	18	5	20	8	4	3

Recent fractures (without any evidence of healing) were seen in 18 of the 57 badgers radiographed (32%); two badgers had fractures at multiple sites. Pelvic fractures were the most common recent fracture (8/18; 44%), and were often multiple. The bones of the forelimb were the second most common site for recent fractures (6/18; 33%) involving the humerus (3 cases), radius and/or ulna (2 cases), and shoulder (1 case). Four fractures to the hindlimb involved the femur (2 cases) and tibia and fibula (2 cases). Nine (9/18; 50%) badgers with recent fractures also had either soft tissue injuries or evidence of chronic bone damage. Almost all fractures would have required surgical fixation and were therefore almost all badgers with these injuries were euthanased for welfare reasons. A single non-displaced radial fracture associated with an undamaged ulna was successfully treated using external coaptation and healed adequately within four weeks.

Dislocations were present in five badgers (5/57; 9%), two of which had concurrent recent fractures. The dislocations occurred at different places; sacro-iliac joint, lumbar spine, hip, elbow and tarsus and all these badgers were euthanased for

welfare reasons because of their injuries.

Ten badgers with radiographic lesions (10/57; 18%) had evidence of bone lysis and/or proliferation, occurring at multiple sites in five cases. Seven cases had changes consistent with healing and remodelling of old fractures. Three animals with healed fractures had concurrent radiographic lung changes and one had a digit lesion. Four badgers had much more extensive bone remodelling than would be expected with fracture healing alone and the large radiolucent lytic areas accompanied by areas of boney proliferation were typical of osteomyelitis rather than fracture healing, although neoplasia could not be ruled out without histopathological examination. In two cases these changes were limited to a digit and the shaft of the femur respectively, most likely arising from local damage possibly as a result of a bite. The other two cases had such extensive bone remodelling involving multiple joints that the likely aetiology was considered to be haematogenous spread to joints or physes but no primary focus was detected. There were no concurrent radiographic lesions in the lungs of these two badgers.

Two animals had radiographic evidence of pneumothorax and one had a ruptured diaphragm. Radiographic lung changes (6 cases; 11%) were all generalised and diffuse but were of two distinct types. Four animals had a diffuse alveolar pattern in the lungs consistent with either pneumonia or pulmonary congestion. In the second group of animals (2 cases) the lung pattern comprised small focal radiodense areas. Four cases had lung changes as well as other radiographic findings. Lungs were not manually inflated for radiography, instead where possible they were taken on inspiration, the limitations of this approach for the identification of lung lesions will be discussed.

Two animals had evidence of stomach or intestinal rupture. Other cases had radiographic changes associated with gastric wall thickening (1 case), and gaseous distension of the intestines (2 cases) associated with gut stasis rather than obstruction. One female badger was pregnant.

Radiographic findings were considered in relation to where the 35 badgers had been

found (Table 4.10). There were no significant differences in radiographic findings between the locations, however most badgers with fractures (11/16; 69%) and dislocations (3/5) were found at the roadside. Both badgers with pneumothorax and the three badgers with rupture involving gut and diaphragm were also found at the roadside.

Table 4.10 Classification of radiographic abnormalities in 35 badgers according to the location in which the badgers were found

Location (number of badgers)	Radiographic abnormality					
	Fracture	Dislocation	Bone lysis / proliferation	Abnormal soft tissue density	Abnormal soft tissue lucency	Rupture
Field (3)	2	0	0	1	0	0
Road (20)	11	3	4	2	3	3
Garden (4)	3	0	2	1	1	0
Domestic building (2)	0	1	1	1	0	0
Farm building (5)	0	1	0	0	0	0
Other (1)	0	0	1	1	0	0
TOTAL (35)	16	5	8	6	4	3

4.3.6 Clinical findings

Cases were classified according to the major clinical finding following review of the clinical examination findings, routine haematology and biochemistry results and radiographic data (Figure 4.10) for; all animals recorded, male animals and female animals. Female badgers more commonly suffered acute trauma ($P < 0.001$), whilst male badgers suffered more chronic disease ($P < 0.05$) and bite wounds only ($P < 0.05$).

Clinical findings were then considered in relation to where the animal had been found (Figure 4.11). As would be expected badgers found at the roadside had more commonly suffered acute trauma ($P < 0.001$) than those found elsewhere.

Figure 4.10 Classification of clinical data for all badgers, male and female animals

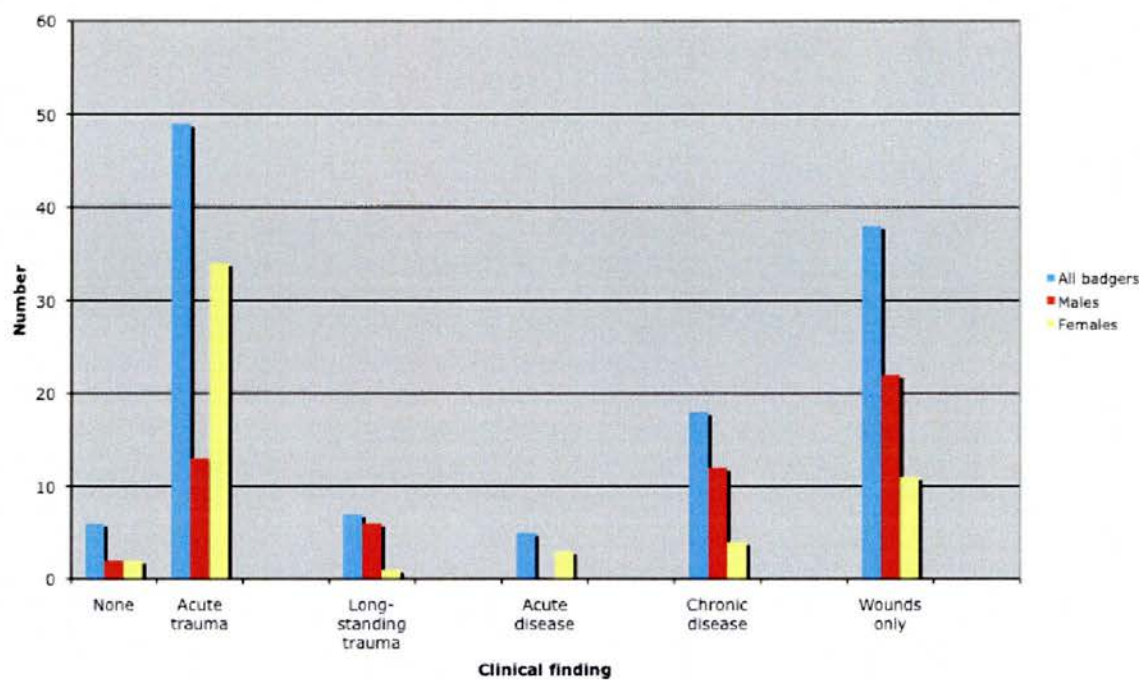
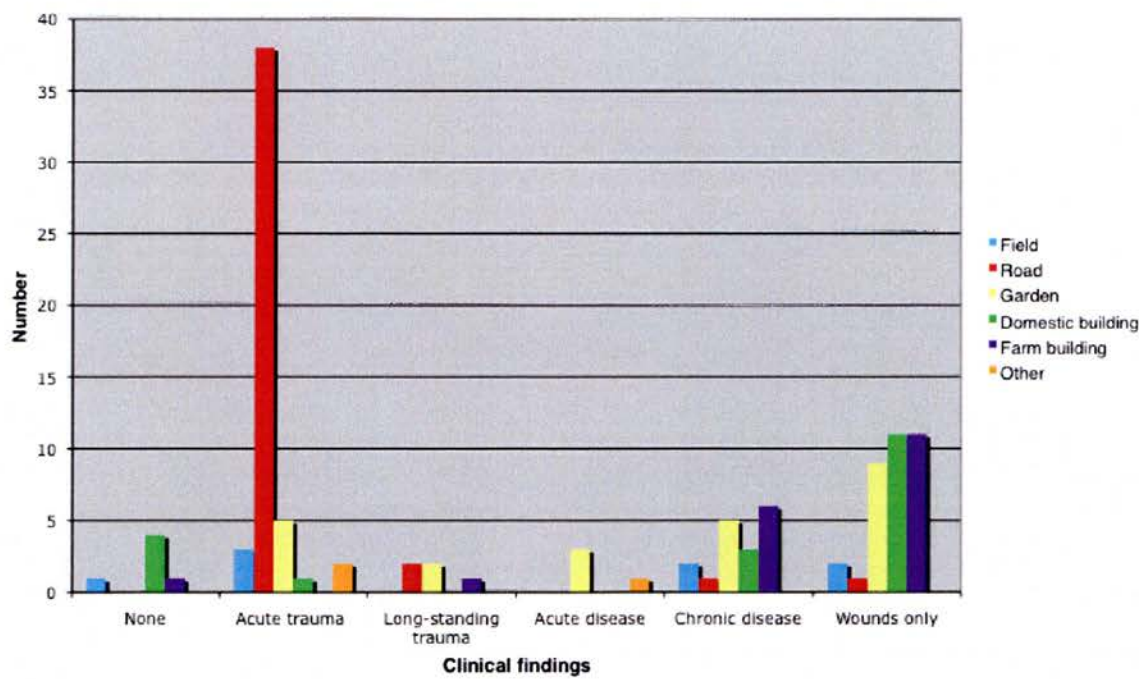


Figure 4.11 Clinical findings in relation to the location in which badgers were found



Finders reported badgers to have one of nine presenting signs in 121/123 cases as previously illustrated in Figure 3.4. These presenting signs were compared to veterinary clinical findings (Table 4.11). It is not possible to determine the extent to which location influenced the presenting description of the casualty badger given by members of the general public.

Table 4.11 Clinical findings in relation to the presenting signs described by the finder

Reason for presentation	Clinical finding					
	Non	Acute trauma	Long-standing trauma	Acute disease	Chronic disease	Bite wounds only
Neurological signs (n=5)	0	0	0	3	2	0
Caught / entangled (n=2)	1	0	0	0	0	1
Collapsed / recumbent (n=12)	0	5	1	2	2	2
Lame (n=4)	0	2	0	0	1	1
Paraplegic / dragging legs (n=7)	0	6	1	0	0	0
Presumed / known RTA (n=41)	0	36	2	0	2	1
Thin (n=5)	0	0	0	0	4	1
Wounds only (n=22)	0	0	0	0	5	17
No signs (in wrong place) (n=23)	5	0	3	0	2	13
TOTAL (n=121)	6	49	7	5	18	36

4.3.7 Body systems affected

The animals were classified according to the body systems that were involved in their main clinical problem as categorized in Table 4.2. All badgers, males and females were considered in this way (Figure 4.12). Female badgers had more musculoskeletal damage than males ($P < 0.05$), whilst males had more multisystem disease ($P < 0.05$) and more frequently bite wounds only ($P < 0.05$).

Figure 4.12 The major body systems clinically affected in adult badger casualties

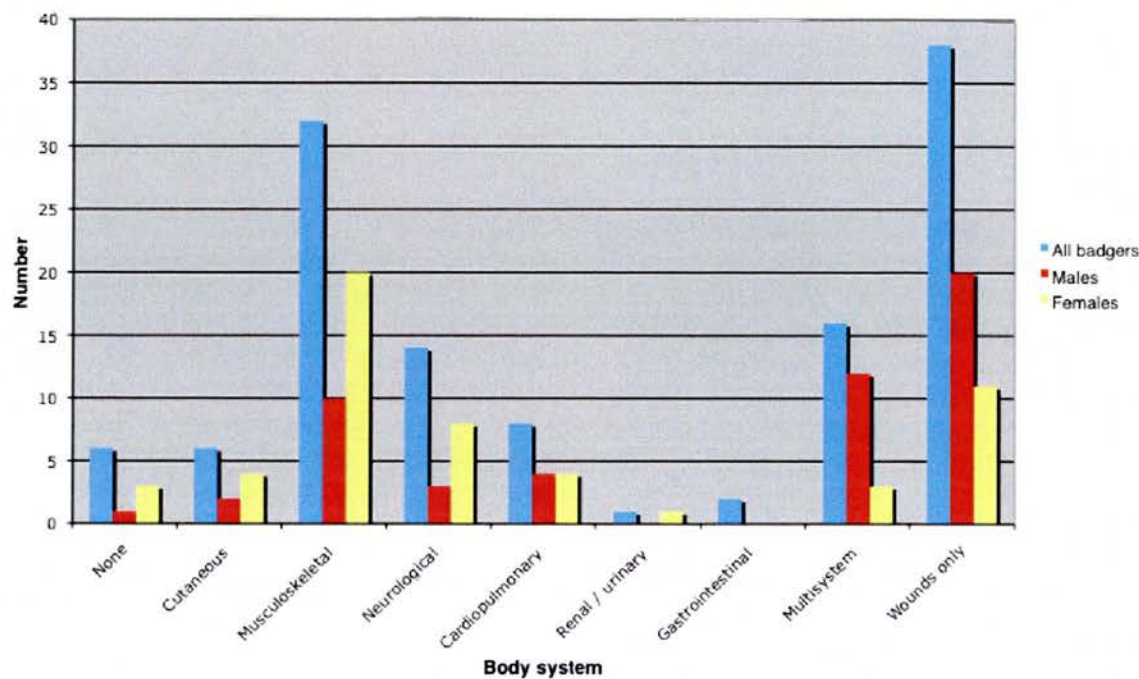


Table 4.12 Major clinical finding compared to affected body systems in adult badger casualties

Body system affected	Clinical findings					
	Non	Acute trauma	Chronic trauma	Acute disease	Chronic disease	Bite wounds only
Non (n=6)	6	0	0	0	0	0
Cutaneous (n=6)	0	6	0	0	0	0
Musculoskeletal (n=32)	0	25	6	0	1	0
Neurological (n=14)	0	7	1	4	2	0
Cardiopulmonary (n=8)	0	8	0	0	0	0
Renal / urinary (n=1)	0	1	0	0	0	0
Gastrointestinal (n=2)	0	2	0	0	0	0
Systemic (n=16)	0	0	0	1	15	0
Bite wounds only (n=38)	0	0	0	0		38
TOTAL (n=123)	6	49	7	5	18	38

The clinical findings for each case were also considered in relation to the body systems involved (Table 4.12). The musculoskeletal system was associated with acute trauma in 51% of cases ($P < 0.001$) and chronic trauma in 86% cases. Multisystemic involvement was nearly always (94%) associated with chronic disease. The numbers of cases were too small to allow further statistical analyses.

4.3.8 Clinical descriptions of cases

The case records described clinical findings associated with three main conditions; acute trauma resulting from RTA, chronic debilitating disease, and bite wounds. Clinical descriptions of bite wounds are discussed in Chapter 5 and described in Table 5.6. A summary of the features of clinical descriptions associated with RTAs are given in Table 4.13, descriptions related to bite wounds in these cases have not been included.

Table 4.13 Clinical descriptions associated with RTA injuries

Clinical descriptions of findings in RTA cases (number of cases)
Palpable fractures of limbs including scapula, tibia and fibula, radius and ulna, femur (8)
Soft tissue injuries to head including lacerations and friction injuries (8)
Friction wounds and cuts to limbs (7)
CNS signs including concussion, central nervous depression and head tilt (4)
Loss of hindlimb reflexes and use (paraplegic) (3)
Pelvic instability including crepitus and malalignment on palpation (3)
Epistaxis (2)
Ocular damage including conjunctivitis and corneal abrasions (2)
Palpable cranial abdominal trauma including pain and abnormality on palpation (2)
Visible bruising to limbs (2)
Loss of all limb reflexes and use (tetraplegic) (1)
Palpable abdominal fluid (haemoabdomen) (1)
Palpable dislocation of limbs including hip (1)
Palpable jaw fracture (1)
Pneumothorax suspected on auscultation (1)
Ruptured diaphragm suspected on auscultation and palpation (1)

Animals with chronic disease also showed a variety of clinical signs as summarized in Table 4.14, descriptions of bite wounds in these cases have not been included. A large number of animals with chronic disease had bite wounds as discussed in Chapter 5. The clinical findings specifically related to those animals testing positive for *M. bovis* infection are discussed in Chapter 6.

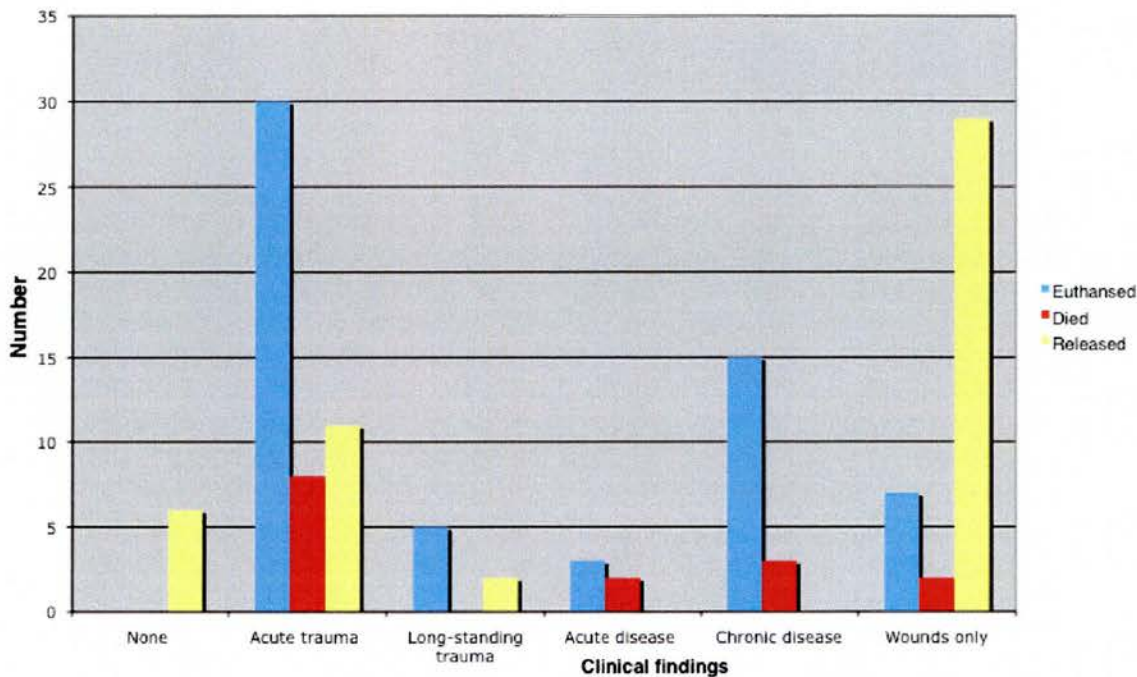
Table 4.14 Clinical features of chronically diseased badgers

Clinical descriptions of findings in chronic disease cases (number of cases)
Palpable thickening of joints (5)
Ocular damage including corneal puncture, 'end stage' eye, cataract (3)
General lymphadenopathy (2)
Overgrown front claws (2)
Palpable thickening of long-bones (2)
Respiratory signs including dyspnoea, reduced air movement (2)
Swelling of nail-beds or digits (2)
Bone swelling around teeth (1)
Diarrhoea (1)
Haematuria (1)
Melena (1)
Paraphimosis (1)
Proliferative papilloma like skin growth (1)
Vaginal discharge (1)

4.3.9 Outcomes

The clinical findings were considered in respect to whether the badger was euthanased, died or released (Figure 4.13). 60 badgers were euthanased for welfare reasons. Badgers suffering acute trauma were significantly more likely to be euthanased than those with other clinical findings ($P < 0.01$) and this category accounted for 50% of cases. Badgers with chronic disease were also significantly more likely to be euthanased for welfare reasons ($P < 0.01$) and accounted for 15/60 (25%) of cases. Approximately half (53%) of the badgers that died unexpectedly in captivity had signs of acute trauma, although this was not a statistically significant finding due to the small sample size. Badgers with bite wounds only were significantly more likely to be released ($P < 0.001$) than those released with other clinical findings. Significantly fewer ($P < 0.01$) badgers with acute trauma (11/48; 23%) were released than the other categories. The clinical impact of bite wounds is further discussed in Chapter 5 and further information on the rehabilitation and release of the cases is given in Chapter 7.

Figure 4.13 Rehabilitation outcome for 121 badgers with varying clinical findings



4.4 Discussion

Body condition in the present study was recorded on a four-point scale by visual examination and palpation of bony landmarks such as the transverse processes of the lumbar vertebrae, scapulae, pelvis and ribs. Other methods of assessing body condition in wildlife have been used, such as the calculation of indices based on length and weight of individuals, as illustrated for the Eurasian otter (*Lutra lutra*) (Simpson, 1997). Condition scoring is considered a more useful method of assessing body nutritional status where a group of animals are not uniform in size and is commonly used in livestock species such as sheep (Russel, 1984). Badgers presented in all four categories of body condition score (poor, fair, good and very good) although the majority (95.5%) of cases were in the first three categories. Similar numbers of animals were found to be in good condition (35.7%) as were in poor condition (38.4%), suggesting not all cases were chronically ill and debilitated. Overall female badgers generally were in better condition than males, although there was considerable seasonal variation.

A seasonal variation in badger weight has been described by other authors related to the availability of food, which is lower in the summer and greater in the autumn (Kruuk and Parish, 1983; Cheeseman *et al.*, 1987; Cresswell *et al.*, 1992; Clifton-Hadley *et al.*, 1993; Delahay *et al.*, 2006a), when badger weights consequently increase as a result of fat deposition (Cresswell *et al.*, 1992; Zalewski *et al.*, 2007). Body mass has been shown to decline to a greater extent in female animals over the summer months than in males as a result of the demands of lactation (Cresswell *et al.*, 1992; Clifton-Hadley *et al.*, 1993). Cresswell *et al.* (1992) considered omental and renal fat deposits in badgers post-mortem and showed that females had minimum fat depositions in June-September, whilst males showed no such summer decline; whole body mass in females also declined more in the summer. The same seasonal effect was seen in female badgers in the current study population with significantly more animals in poor condition July-September and in good condition January-March. Seasonal trends were less obvious in males with most in poor condition from January to March contrary to other research. These differences may be as a result of several influences including factors that select animals from the wild population for presentation to veterinarians. The seasonality of body condition in males appears to mirror the seasonality of bite wounds, which is a common reason for male badgers to be presented to veterinary practices and wildlife charities (5.3.6).

Body condition scores did not differ significantly between the locations in which badgers were found. Badgers admitted as a consequence of trauma, such as RTA, would be expected to have higher condition scores than those found in other locations such as buildings because terminally ill badgers may more commonly enter farm buildings than healthy badgers (Cheeseman and Mallinson, 1981). The results of the present study however, questions this theory because some badgers in poor condition were involved in RTA and other badgers in good condition were found in farm buildings. The suggestion (L. Corner, *pers. comm.*) that debilitated badgers infected with *M. bovis* might be more prone to RTA may be supported in some cases by the current data. Furthermore, badgers in buildings could be those stronger badgers able to survive RTA or bite wounds and escape to a secure place.

Body condition was a good prognostic indicator with significant positive correlation with release. Outcomes will be discussed further in Chapter 7.

Dental findings were consistent with the natural lifestyle of the badger and the function of the teeth involved. Incisors used for prehension and biting were frequently missing or fractured as a result of natural wear and tear. Canine teeth used for biting a variety of both hard and soft foods in the omnivorous badger diet, and fighting with other badgers, were frequently fractured, and occasionally missing. Canine teeth were also damaged in RTAs with findings similar to the physical orodental conditions seen in domestic dogs and cats in areas of high traffic density (Eriksen, 2007) and not dissimilar to dental findings in a post-mortem study of Eurasian otters (*Lutra lutra*) where fractured canine teeth were the most common finding (Simpson, 1997). Molar teeth used for mastication and grooming were more commonly worn than missing consistent with our knowledge of dogs and cats (Eriksen, 2007). Such molar tooth wear does not normally cause pathological changes to the pulp or periodontal tissues and subsequent disease processes.

Variations in premolar number have been reported in badgers, with the first premolar either vestigial or absent (Neal and Cheeseman, 1996). Seven badgers had missing premolar teeth, although it was not known if this was as a result of previous trauma or a genuine absence of dentition; one animal had a vestigial premolar tooth. The presence of vestigial premolars was much lower than the 94% prevalence suggested in a study of badger skulls (Hancox, 1988a).

Dental caries, where there is demineralisation of the calcified tissues of the teeth as a result of acid production from bacterial fermentation, is uncommon in domestic dogs compared to man (Caiafa, 2007). Dental caries have been reported in normal free ranging badgers (Andrews and Murray, 1974) especially in older animals (Lewis, 1997b) but such changes were not noted in any of the study badgers. The necessity for treatment or removal of damaged teeth in casualty badgers prior to release has been previously discussed (Cousquer, 2002; Mullineaux, 2003a). In this study of 123 badgers only two casualties had teeth removed as a result of traumatic avulsion. This study further showed that badger casualties do not need to be treated in the same way

as domestic dogs and cats and extensive dental work to remove or repair damaged or worn teeth, is not essential for the badger's survival upon release.

The number of teeth fractured or missing increased with greater tooth wear consistent with the natural ageing process. Although significantly less dental abnormalities were found in those badgers with no tooth wear (grade 0), damaged and missing teeth did occur in badgers of all ages suggesting trauma as a contributing factor. Surprisingly, fractured and/or missing teeth did not adversely affect body condition score. In post-mortem studies tooth wear and tartar formation were the only obvious causes of emaciation in some badgers (Gallagher and Nelson, 1979) and fractured teeth have been associated with fatal mandibular osteomyelitis (Neal and Cheeseman, 1996). While severe dental disease has been a reason for euthanasia of casualty badgers (Cousquer, 2002; Mullineaux, 2003a), dental disease in this study was never the major reason for euthanasia.

Badgers frequently presented with evidence of bite wounds after interactions with other badgers (conspecific wounding) rather than from attacks by dogs or other animals. Dog bite wounds have a different distribution to badger-related wounds and result in local cellulitis and systemic infection (Mullineaux, 2003a). Bite wounds occurred in over half the badger casualties admitted and was the sole reason for admissions in many cases (3.3.3). Since bite wounds occurred so frequently their significance and impact on clinical outcome was questioned and is discussed in Chapter 5.

Most studies of badger blood analytes have concentrated upon variations related to adult and juvenile physiology (Mahmood *et al.*, 1988; Domingo-Roura *et al.*, 2001; Winnaker *et al.*, 2008). There have been few attempts to investigate the clinical application of blood metabolite analyses to diseases other than tuberculosis (Mahmood *et al.*, 1988; Chambers *et al.*, 2000)

Many badgers in this clinical study had several concurrent clinical conditions of varying chronicity. Clinical examination, together with the limited clinical history, aided interpretation of the blood results. Interpretation of the blood results was however, hampered by the lack of comprehensive normal values for badgers and the

reliance upon canine values. Since the clinical work in the present study was completed a more comprehensive study of badger blood values has been published from the Woodchester Park field research area (Winnaker *et al.*, 2008). This study has been criticised because the study population is infected with *M. bovis* (Denny, 2008). However, the values are likely to be typical for wild badgers in that area and not unrepresentative of 'normal' badgers within a free ranging population (Delahay, 2008). In contrast blood values from the VLA vaccine research project, also made available to the author, may represent unnaturally healthy well-fed animals (Appendix 2.8). These data illustrate the difficulty in obtaining 'normal' values for wild badgers. When considered retrospectively these more recent studies did not influence interpretation of the blood results, nor would have influenced the outcomes for individual badgers where blood tests were part of the overall clinical assessment and decision-making process before release or euthanasia.

Plasma amylase has not been described previously in badger studies, therefore the normal canine amylase range was used for interpretation. Almost all badgers (92%) had amylase concentrations below the canine reference range. Clinical reasons for low amylase concentrations include; exocrine pancreatic insufficiency, pancreatic necrosis, and use of corticosteroids (Bush, 1991). It was considered unlikely that a large number of badgers could be affected by these conditions and this was supported by the lack of appropriate clinical signs. Canine plasma amylase reference ranges are therefore considered unsuitable for interpretation of badgers.

The large range in plasma glucose concentrations highlighted the limitations of this measurement in a clinical study of wildlife. Plasma glucose concentrations may increase following physiological stress or excitement (Bush, 1991), which are difficult to control in captive badgers and made these values impossible to differentiate from clinical hyperglycaemia. Additionally the use of ketamine for anaesthesia may result in changes in blood glucose concentrations, including hyperglycaemia (Sharif and Abouazra, 2008). Hypoglycaemia may be caused by starvation as well as clinical disease including neoplasia, hepatic dysfunction and sepsis (Bush, 1991). Some glucose values were so low as to suggest sampling errors rather than metabolic disease.

Elevated plasma urea and creatinine concentrations may indicate pre-renal factors such as diet and dehydration, as well as indicating renal functional problems in acute or chronic disease, potentially including bTB. Mean urea concentrations in all five clinical categories in the present study were above the normal canine range, but were similar to mean values reported by Winnacker *et al.* (2008). Badgers often have a protein rich diet from eating earthworms (*Lumbricus terrestris*) (Kruuk and Parish, 1985; Neal, 1988) and this has been considered the reason for very variable urea concentrations (Winnacker *et al.*, 2008). Badgers in the chronic trauma category had lower mean urea values than other badgers possibly as a result of reduced protein intake.

Creatinine is considered a better indicator of renal function than urea and is only confounded by body muscle. Mean creatinine concentrations for all the clinical groups of badgers were found to be within canine normal ranges but generally lower than those suggested by Winnacker *et al.* (2008). This may be a result of lower body muscle in the present population of casualty badgers as a result of debilitation or disease. Significantly increased creatinine concentrations have been found by other authors in association with tuberculosis (Chambers *et al.*, 2000). This study however, found the lowest mean creatinine concentrations in badgers with chronic disease.

Although there is debate over the usefulness of the urea/creatinine ratio in dogs and cats compared with man (Squires, 2005), the ratio may compensate for high protein diets or rule out gastrointestinal haemorrhage as a source of urea, as well overcoming the influences of varying body muscle mass (natural or as a result of disease) upon creatinine. The urea/creatinine ratio found in the present study was similar to previous reports in badgers (Winnacker *et al.* 2008) but much higher than that suggested for dogs (Bush, 1991) probably as a consequence of diet.

It was difficult to differentiate between pre-renal elevations in plasma urea and creatinine such as dehydration, and renal failure. Urinalysis, in particular the measurement of urine specific gravity indicating the kidney's ability to concentrate urine, is commonly used in clinical practice as a diagnostic tool (Wamsley and Allerman, 2007). Plasma sodium and total protein concentrations and RBC counts

may also be useful in differentiating between pre-renal effects and true renal disease but these concentrations were often influenced by other clinical conditions affecting the badgers, for example serum albumin concentration was often low as a result of chronic disease while RBCs were low as a result of haemorrhage following trauma. Urinalysis, especially following free flow urine collection or bladder compression, is actively discouraged in badgers in veterinary practices due to the risk of *M. bovis* infection (Mullineaux, 2003a). Cystocentesis would allow simple tests, such as measurement of specific gravity and use of urine reagent test strips, without notable health and safety risk and such sampling would greatly aid the interpretation of azotaemia in badgers.

Plasma albumin concentrations fall as a result of either reduced protein synthesis by the liver and/or increased protein loss seen in many chronic diseases, whilst plasma globulin concentrations increase in response to antigenic stimulation (Bush, 1991). A large number of badgers in the present study presented with hypoalbuminaemia and hyperglobulinaemia compared to normal canine ranges. Interpretation of these protein concentrations using the available badger blood values only exaggerated this effect. Mean values in the more extensive Woodchester Park study (Winnacker *et al.*, 2008) also appear to support this finding.

Badgers in the present study had a low mean albumin/globulin ratio of 0.48 (+/- 0.1) suggesting that the study badgers had low albumin and/or high globulin concentrations as a result of their injury or disease status. The significance of plasma proteins in relation to bite wounds and bTB are discussed further in Chapters 5 and 6 respectively. The high incidence of bite wounds in the study population (55%) is considered to be an important factor affecting plasma protein concentrations. Other authors have found significant effects on albumin/globulin ratios associated with both time of year and body condition (Domingo-Roura *et al.*, 2001), both factors that are significantly linked to bite wounds as well as nutritional status.

Plasma calcium concentrations were adjusted for albumin concentration to compensate for the very low albumin concentrations seen in many badgers. Before adjustment 15% of badgers had low calcium concentrations, however all badgers had

adjusted calcium concentrations within the normal canine range. Other authors have suggested that mean calcium concentrations are lower in badgers than dogs (Winnacker *et al.*, 2008) and some have found lower plasma calcium concentrations in tuberculous badgers compared with healthy animals (Chambers *et al.*, 2000). It is unclear whether the importance of low albumin concentrations in debilitated badgers has been considered in other studies because this would affect the calcium concentrations in free-living populations.

A higher mean plasma calcium concentration was found in badgers with chronic trauma, which may be associated with bone lysis and remodelling. Hypercalcaemia was not evident in any groupings including those badgers with chronic disease. The possible association between hypercalcaemia and TB is discussed in Chapter 6.

All the badgers in the study were sedated for collection of blood samples unless they were severely debilitated and easily restrained. The extent to which sedatives and general anaesthetics used for badger restraint affected PCV and RBC count could not be determined because it would not be possible to collect samples safely without chemical restraint. All the mean haematological parameters obtained from badgers were within normal canine ranges but two of the classifications (chronic disease and bite wounds) had PCV and RBC values below the reference badger range and other studies (Winnacker *et al.*, 2008). Anaemia may be associated with chronic disease, including chronic inflammation (Bush, 1991). Lower RBC counts have been associated with bTB in captive badgers (Mahmood *et al.*, 1988), however RBC counts were found to be higher in bTB in a study of wild badgers (Chambers *et al.*, 2000). In man haematological parameters vary greatly between individuals throughout the course of the disease although a normocytic anaemia is commonly seen (Hussain *et al.*, 2004).

There was no haematological evidence of significant hemorrhage in the cases of acute trauma, which were mostly RTAs. This correlates with a lack of major haemorrhage seen on clinical and radiographic examinations. It was not possible to assess mucous membrane colour, heart rate or peripheral pulses in most cases prior to sedation, which would affect these parameters, as a result of health and safety

considerations.

There was a large variation in WBC counts in the badgers in the five clinical classifications used in the present study but there was no significant difference between these groupings. While a leucocytosis would be expected in an acute infection such as bite wounds and associated with inflammation (Bush, 1991), badgers with bite wounds occurred in all clinical classifications and the influence of concurrent bite wounds on WBC counts could not be separated from the other clinical conditions. Leucocytosis may occur in chronic infections, although immune responses during the course of natural *M. bovis* infection in badgers (Mahmood *et al.*, 1988; Newell, *et al.*, 1997; Lesellier *et al.*, 2008) and man is variable and is discussed further in Chapter 6.

The majority of radiographic findings were associated with recent traumatic events, often known or suspected RTAs. The range of radiographic findings associated with RTAs was similar to the author's clinical experience and published surveys of domestic dogs (Sigrist *et al.*, 2004; Simpson *et al.*, 2009) and cats (Rochlitz, 2004; Sigrist *et al.*, 2004; Adamantos and Corr, 2007). In domestic cats, injuries sustained in RTA range from minor abrasions and broken claws to life threatening injuries such as spinal cord damage, head trauma and chest injury (Rochlitz, 2004). Not surprisingly the more minor classes of injury described in cats (Rochlitz, 2004) were not observed in badgers presented for rehabilitation since these cases probably escaped the scene of accident. Many lesions such as fractures and dislocation could be identified on clinical examination under general anaesthesia and radiographs were taken to confirm the provisional diagnosis and afford a more accurate prognosis. Fractures of the pelvis, spine and long bones were all encountered, as is frequently the case in domestic small animals (Rochlitz, 2004; Sigrist *et al.*, 2004; Adamantos and Corr, 2007; Simpson *et al.*, 2009). In common with these species (Simpson *et al.*, 2009), polytrauma was a radiographic finding in some badgers.

Thoracic injuries including pneumothorax and ruptured diaphragm were identified on clinical examination and confirmed radiographically. In dogs chest auscultation is considered to be the best way of identifying thoracic injury following blunt trauma,

such as RTA, and a better indicator than respiratory rate (Sigrist *et al.*, 2004). Many sedative drugs and anaesthetic drugs, including medetomidine used in the study badgers, suppress respiratory rate and depth (Murrell, 2007), making auscultation and radiography essential to diagnosis. The chest is the most common area traumatised in dogs suffering blunt trauma (Simpson *et al.*, 2009) with half of dogs presented having thoracic radiographic abnormalities (Sigrist *et al.*, 2004). Pulmonary contusion is the most common cause of dyspnoea in cats involved in RTA, followed by pneumothorax and less commonly diaphragm rupture (Adamantos and Corr, 2007). Four of the study badgers had signs consistent with pulmonary damage on both auscultation and radiography.

Abdominal abnormalities were also seen radiographically, including intestinal rupture. These injuries together with haemorrhage from abdominal organs such as liver and spleen are frequently encountered in RTA cats (Rochlitz, 2004; Adamantos and Corr, 2007). This supports previous reports of healed liver and spleen lesions in badgers found at necropsy and assumed to have resulted from RTA (Gallagher and Nelson, 1979).

Bone lysis and/or proliferation were the second most common radiographic features after long bone fractures. In some instances bone malalignment indicated that these radiographic changes resulted from an earlier fracture whilst in other cases the pathogenesis was less clearly defined. Without histopathology and microbiological analysis it was not always possible to differentiate between healing fractures and other bone pathology such as osteomyelitis and neoplasia (May, 2002).

Haematogenous spread of bacteria causing osteomyelitis usually involves the physes in neonatal animals. In dogs and cats it is very uncommon, and is often accompanied by systemic signs of illness (May, 2002) requiring careful differentiation from metaphyseal osteopathy (Dunn *et al.*, 1992). Haematogenous osteomyelitis may be monostotic (affecting one bone) or polyostotic (affecting multiple bones). The polyostotic nature of bone lesions in some of the badgers would suggest haematogenous spread from a point of infection, possibly a bite wound, at a time when physes were still open, at under 18 months old (Page, 1993). The generalised

distribution of bone lesions in two badgers was consistent with bacteraemia and similar polyarthritis has been described clinically (Lewis, 1997b) and post-mortem (Gallagher and Nelson, 1979), but not attributed to any particular bacterium. The possible significance of these lesions in relation to *M. bovis* is discussed further in Chapter 6. Post-traumatic osteomyelitis in dogs and cats is a more common condition and may occur following surgery, bite wounds (especially in cats), RTA (associated with compound fractures) or gunshot injuries (May, 2002; Langley-Hobbs, 2006). This form of osteomyelitis is usually localised and monostotic. As badgers in the study commonly suffered RTA and bite wounds these were logical explanations for monostotic bone lesions. Lesions associated with chronic osteomyelitis include; periosteal new bone proliferation, irregular patterns of bone lysis and sclerosis (May, 2002) all of which were features of the radiographs of badgers with bone lesions. Sequestration or involucrum formation which may also occur (May, 2002) were not seen in the badgers. Studies of bite wounds in otters have not reported osteomyelitis as a common feature, with most wounds involving the feet, perineum and head (Simpson 1997; Simpson, 2006).

Several badgers had radiographic lung lesions that were not consistent with trauma. To obtain maximum lesion definition, thoracic radiographs should be taken when the lungs are fully inflated either at maximum inspiration or upon manual inflation in anaesthetised intubated animals (Dennis, 2003). The badgers in the present study were sedated and not routinely intubated for practical reasons including risk assessment of the potential contamination of anaesthetic equipment with *M. bovis*. Furthermore, it was difficult to take inspiratory films because of the respiratory suppressive effects of medetomidine (Murrell, 2007). Despite these potential limitations radiographic abnormalities were detected in the chest of six badgers. Without necropsy confirmation, the diffuse changes in four badgers were considered to represent minor pulmonary haemorrhage following RTA. In two badgers focal radiodensities throughout the whole lung field were consistent with calcified lesions described in badgers at post-mortem examination resulting from granulomata caused by lungworm (*Aelurostrongylus falciformis*), focal lesions associated with bTB and lesions associated with adiaspiromycosis (*Emmonsia* (*Chrysosporium*) *crecens*)

(Gallagher *et al.*, 1989). The significance of these lesions with respect to potential *M. bovis* infection is discussed further in Chapter 6.

Acute trauma largely associated with RTA, bite wounds, and to a lesser extent chronic debilitation and disease, were the most common clinical findings in badger casualties in the present study. These findings are consistent with other reports (Gallagher and Nelson, 1997) that found bite wounds, RTA and bTB the most common conditions at necropsy.

The reasons for presentation described by the finders of casualty badgers were largely a true representation of the main clinical signs, although many badgers had more than one clinical condition when examined. Female badgers were presented significantly more commonly than males with signs of trauma (mostly RTA) involving predominantly the musculoskeletal system. Significantly more male badgers presented with bite wounds and chronic disease affecting more than one organ system than female badgers.

The literature review describes a large number of infectious diseases reported in badgers but the clinical diagnosis of such conditions in this study was limited by the cost of testing for specific diseases and the presentation of badgers in the agonal stages of disease where immediate euthanasia was necessary for welfare reasons. There was little evidence of acute disease perhaps because these animals die away from public view and were not presented for treatment. Although malicious and accidental poisoning events in badgers have been reported (Neal and Cheeseman, 1996; Cousquer 2003) there was no evidence of poisoning in the present study. Reports in the literature suggest that bTB is a significant disease condition of badgers with weight loss and general debilitation the only reported clinical signs (Clifton-Hadley, 1993; de Lisle *et al.*, 2002). Other clinical signs attributable to tuberculosis and the limitations of testing definitively for *M. bovis* infection are further discussed in Chapter 6.

Although bTB is considered the most important disease affecting badgers in Britain (Cheeseman *et al.*, 1989), RTA accounts for around half the deaths of free-ranging adult badgers (Gallagher and Nelson, 1979, Cheeseman *et al.*, 1987; Cheeseman *et*

al., 1988; Neal and Cheeseman, 1996). A necropsy survey of otters also found RTA to be the most common cause of death (Simpson, 1997). The sample populations in many of these studies are considered biased since dead animals are most easily observed and collected from the roadside (Neal and Cheeseman, 1996). In the present study of live badgers presented for treatment, badgers other than those at roadside badgers were presented, however the close relationship between RTA and man undoubtedly biased the current sample population. RTA also caused most of the acute clinical signs and these badgers carried a grave prognosis with 64% of badgers found at the roadside euthanased for welfare reasons. The radiographic findings clearly illustrated the extent of trauma suffered from RTA and such injuries, many of which would have required complicated orthopaedic surgery, were not suitable for treatment due to the extended convalescence, frequent drug administrations and problems associated with the use of surgical implants, as will be discussed in Chapter 7. RTA was therefore a significant cause of death in the study population; bite wounds (Chapter 5) and bTB (Chapter 6) will be discussed in the chapters that follow.

4.5 Summary

The most significant clinical findings in the present study were bite wounds, RTA, and chronic disease. A thorough clinical examination under sedation was important in differentiating between those badgers with conditions with a good prognosis and those animals that should be euthanased for welfare reasons. Body condition at examination was a useful and easily performed prognostic indicator. Fractured teeth were a frequent finding, but did not appear to present significant problems or influence prognosis.

Bloods sample analysis added little new information to the clinical assessment because multiple disease conditions could present in the same badger. The absence of badger reference ranges hindered interpretation of results. Urine samples are not routinely collected from badgers in veterinary practices but following prudent consideration of health and safety issues, urinalysis following cystocentesis is likely to add to the interpretation of azotaemia.

Radiographs did not influence the clinical decision in most cases of acute trauma since injuries were detected on clinical examination, and most injuries carry a grave prognosis. Radiographs are useful in chronically debilitated badgers, although thoracic images should be taken under general anaesthesia with the chest inflated, if practically possible to aid image quality and accurate interpretation. Post-mortem examination and histopathology would be essential in any further studies for diagnosis of many conditions including chronic bone lesions. Injuries suffered in RTA appear to have a major effect upon prognosis and are a common reason for euthanasia. Bite wounds and tuberculosis are discussed further in Chapters 5 and 6.

Chapter 5

Bite wounds

5.1 Introduction

Aggressive behaviour between badgers is regarded as normal interaction both within social groups and between neighbouring groups (Kruuk, 1989; Cresswell *et al.*, 1992; Neal and Cheeseman, 1996). Such behaviour frequently results in conspecific wounding (Macdonald *et al.*, 2004b; Delahay *et al.*, 2006b) which is also termed 'territorial wounding' (Mullineaux, 2003a). The incidence of bite wounds in the free-living badger population shows a seasonal pattern (Gallagher and Nelson, 1979; Cresswell *et al.*, 1992; Delahay *et al.*, 2006b) influenced by their annual reproductive cycle (Cresswell *et al.*, 1992). The age of animal (Macdonald *et al.*, 2004b; Delahay *et al.*, 2006b), sex (Cresswell *et al.*, 1992; Macdonald *et al.*, 2004b; Delahay *et al.*, 2006b), body condition (Macdonald *et al.*, 2004b; Delahay *et al.*, 2006b) and population density (Macdonald *et al.*, 2004b) influence the prevalence of wounds.

Bite wounds commonly affect the rump, head, neck and shoulder areas (Gallagher and Nelson, 1979; Lewis, 1997b; Cousquer, 2002). Both sex and age of animal influence the distribution of bite wounds (Delahay *et al.*, 2006b). Bite wounds become infected with mixed bacterial populations (Gallagher and Nelson, 1979) including *M. bovis* (Gallagher *et al.*, 1976, Gallagher and Nelson, 1979; Clifton-Hadley *et al.*, 1993; Gavier-Widen *et al.*, 2001; Jenkins *et al.*, 2008). Myiasis may be an additional complication in the summer months (Lewis, 1997b).

Bite wounds have also been described as a clinical finding in badgers presented to veterinary surgeons and several methods of treatment have been suggested (Keeble, 1999; Cousquer, 2002; Mullineaux, 2003a). There is little information on the incidence of bite wounds in casualty badgers and their clinical significance in the rehabilitation and release process.

5.2 Materials and methods

Records of 123 badger casualties were completed as previously described (Chapter 2). The badgers were anaesthetised for examination (2.4). Wounds were classified according to their site, number, chronicity and size using the criteria described in Appendix 1.1.7 and illustrated below (Table 5.1), and as previously used by other

authors (Delahay *et al.*, 2006b). Animals were clinically triaged as previously described (2.3); some animals were euthanased at an early stage, others had diagnostic tests performed then received treatment and rehabilitation before release.

Table 5.1 Classification of bite wounds

Category		<i>Head</i>	<i>Neck</i>	<i>Rump</i>	<i>Limb</i>	<i>Body</i>	<i>Inguinal</i>
Number	One						
	Few (2-3)						
	Lots (>3)						
Chronicity	Open (fresh)						
	Open (old)						
	Healed (scar)						
Size	Small (puncture)						
	Medium (gash)						
	Large (gaping)						

Wound swabs, blood tests and radiography were carried out as clinically indicated before February 2004, and on all badgers from February 2004 (2.5). Open wounds were swabbed and samples transported in charcoal media for selective culture for *M. bovis* at the FERA laboratories in York. The same group of animals was also serologically tested for *M. bovis* infection using the Brock indirect ELISA test. It was not possible to have wound swabs cultured for routine bacteriology and sensitivity during the study period, because laboratories were unable to process badger samples. In 2009 the VLA tested four samples taken from badger wounds.

Clinical findings from the badgers were described on the recording sheet (Appendix 1.1) and in clinical summary records (Appendix 1.4). The clinical details allowed the cases to be categorized according to their main or most significant clinical finding. Although these findings are discussed more completely in Chapter 4, they are considered here in an attempt to understand the significance of bite wounds as a clinical condition and their impact upon the success of the rehabilitation process.

Bite wounds were treated alongside any other injuries where the triage process and clinical examination suggested a likely successful outcome. Bite wounds were

treated as described in Appendix 2.7 and previously in other text (Mullineaux, 2003a). Most of the treatment phase was carried out at SWWR under veterinary supervision. Animals were continually assessed and daily records kept (Appendix 1.3). Badgers that failed to respond to treatment were euthanased for welfare reasons. Those badgers that met the release criteria specified (Figures 2.1 and 2.3) were 'hard' released at the location where they were found. Possible outcomes for the rehabilitation process (euthanased, died or released) are considered fully in Chapter 7 and in this chapter with respect to the impact of bite wounds.

5.3 Results

5.3.1 Number of animals with bite wounds

One hundred and twenty one badgers had a record made regarding bite wounds; 67 (55%) had evidence of bite wounds.

5.3.2 Month of admission

There was a marked seasonal effect with most badgers with bite wounds admitted during the three months period from February to April (Figure 5.1). This seasonal trend was similar to those of the whole study group (Figure 3.1).

5.3.3 Gender

A significantly higher percentage ($P < 0.001$) of male badgers 42/54 (78%) had bite wounds than female badgers 19/56 (34%). A seasonal effect associated with bite wound admissions was seen in both genders (Figure 5.2), with a peak in admissions in March. There was a second smaller rise in admissions in the autumn that occurred earlier in females.

Figure 5.1 Month of admission of casualty badgers with and without bite wounds

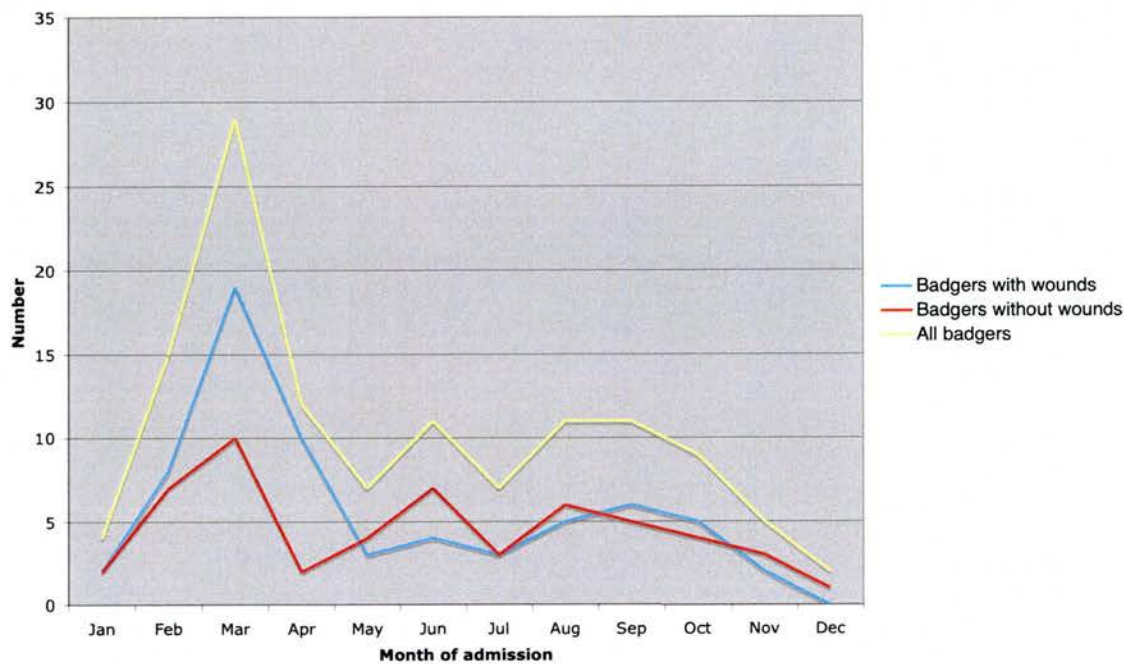
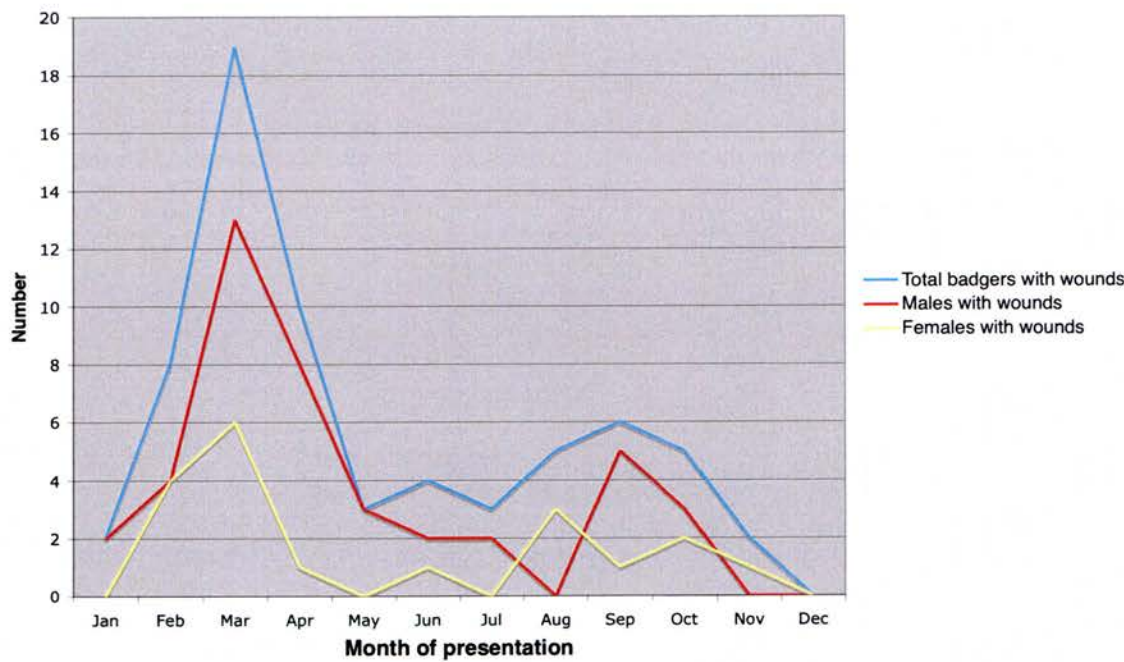


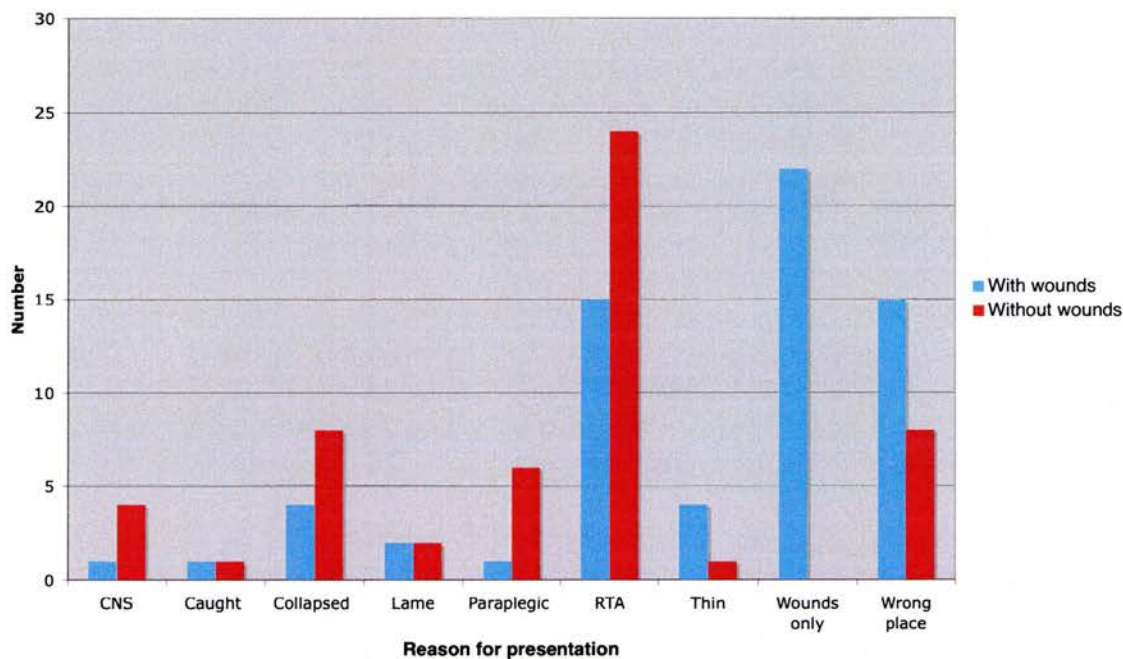
Figure 5.2 Month of presentation of male and female casualty badgers with evidence of bite wounds



5.3.4 Reason for presentation

The reason for presentation, as described by the finder of the casualty animal was recorded in 65/67 badgers with bite wounds and all 54 cases of badgers without wounds (Figure 5.3). Bite wounds did not significantly influence the reason for presentation except in cases where the wounds were the only presenting sign.

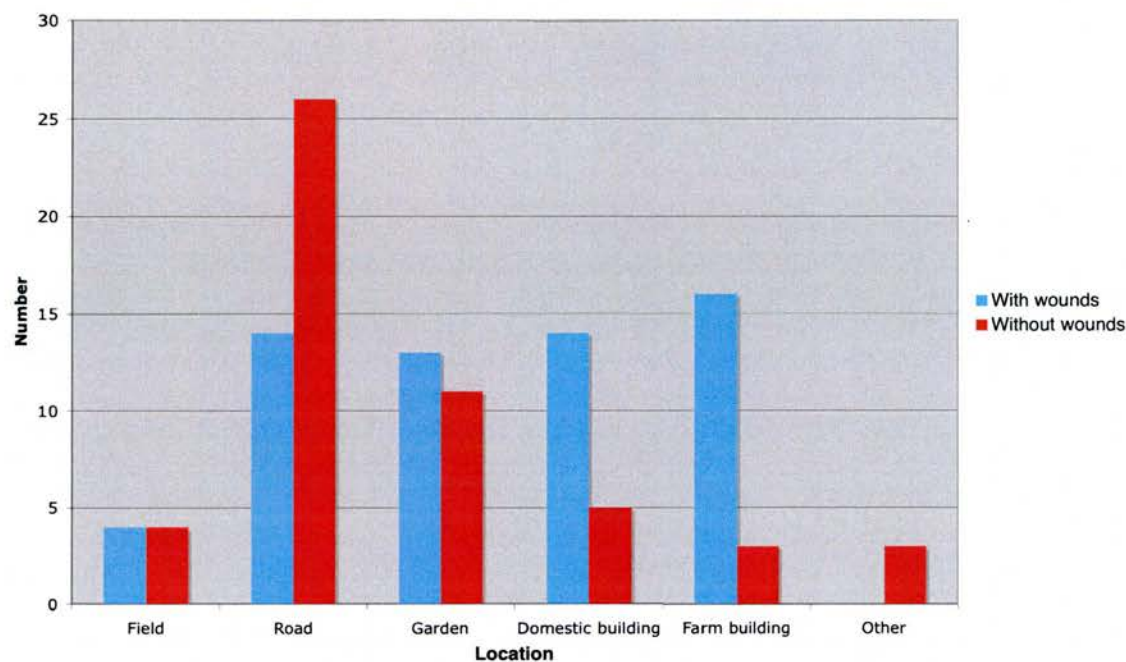
Figure 5.3 Comparison of the primary reasons for admission of adult badger casualties with and without bite wounds



5.3.5 Location where found

Thirty five per cent of badgers found by the roadside had bite wounds, 54% found in gardens, 74% in domestic buildings and 84% in farm buildings (Figure 5.4). Significantly more badgers that were found in buildings ($P < 0.001$) had bite wounds than those found in other locations.

Figure 5.4 Comparison of the locations in which badgers with and without bite wounds were found



5.3.6 Tooth wear

Tooth wear grades, an indication of badger age, were considered for the badgers in relation to the presence of bite wounds (Figure 5.5). Although there was no significant difference in tooth wear in the two categories, there was a trend towards badgers with wounds having higher tooth wear grades.

5.3.7 Body condition score

Badgers without bite wounds tended to have higher body condition scores than those with bite wounds but this difference was not significant (Figure 5.6). Bite wounds were found in 24/43 (55.8%) badgers in poor condition, 15/24 (62.5%) badgers in fair condition, 20/40 (50%) badgers in good condition and 1/5 (20%) of badgers in very good condition.

Figure 5.5 Comparison of tooth wear grades in badgers with and without bite wounds

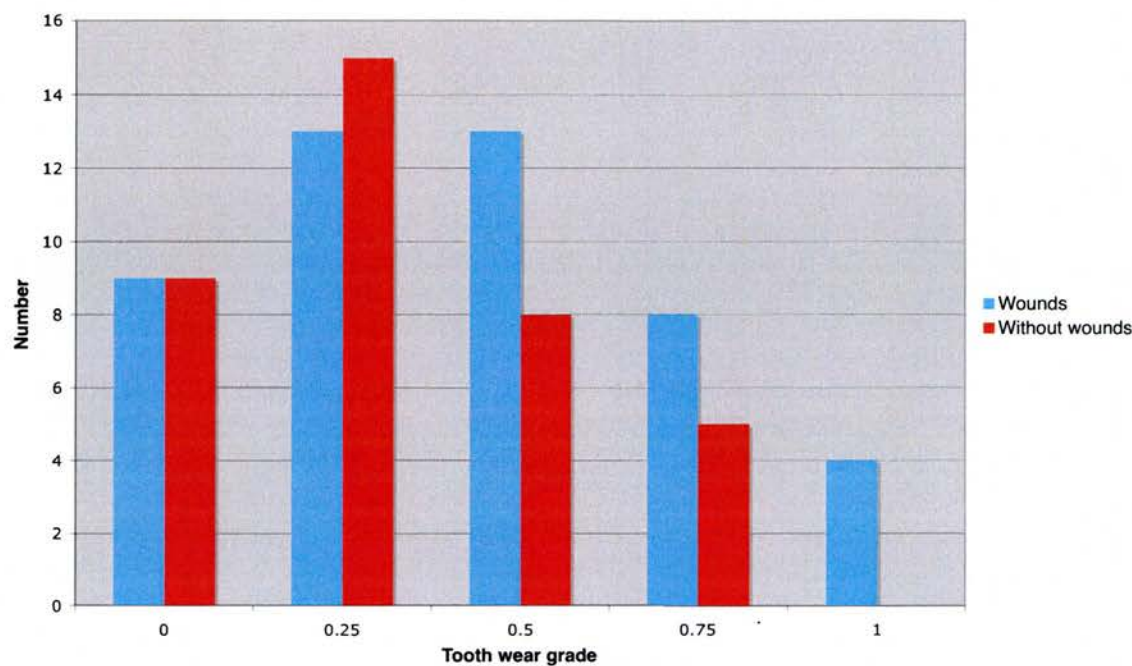
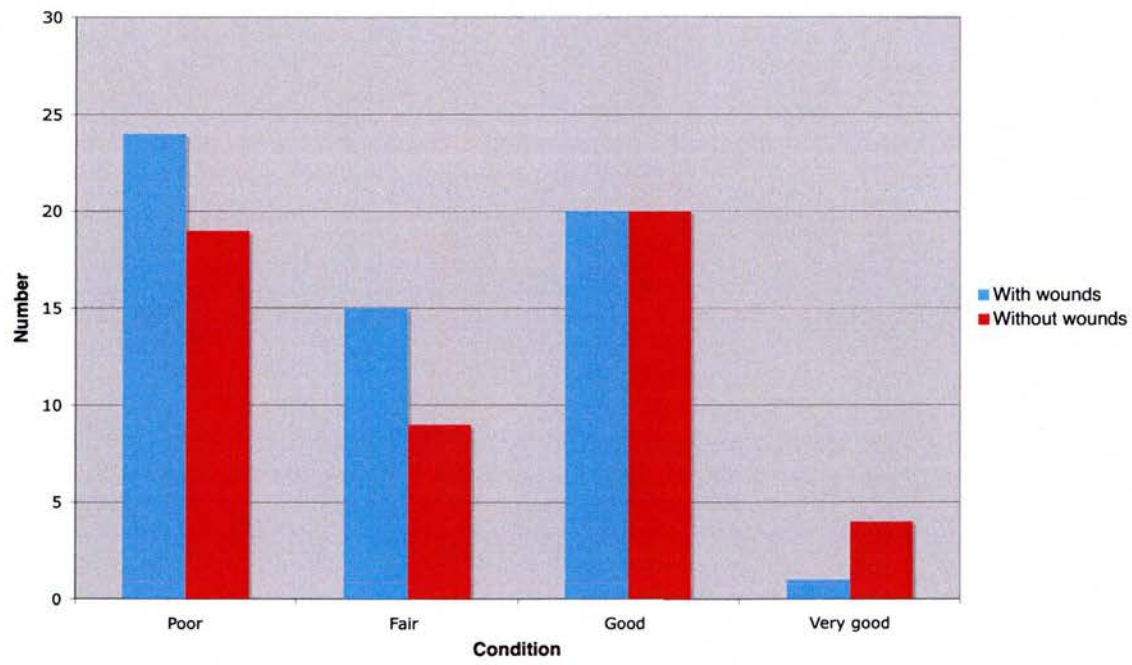


Figure 5.6 Comparison of body condition scores for badgers with and without bite wounds



5.3.8 Body weight

The body weight of the badgers in relation to the presence or absence of wounding is considered in Table 5.2. Badgers with bite wounds had a significantly lower mean body weight ($P < 0.01$) than badgers without bite wounds. Badgers described as juvenile were excluded from these data.

Table 5.2 Comparison of weights for badgers with and without bite wounds

Badger bite wound status	Body weight (Kg)	
	Range	Mean (SD)
With bite wounds ($n=49$)	5.18-12.50	7.71 (1.82)
Without bite wounds ($n=35$)	5.27-15.7	9.12 (2.68)

5.3.9 Site of bite wounds

The body sites at which bite wounds occurred in individual animals were recorded and where wounds occurred at several sites this was described as ‘multiple’ (Figure 5.7). The rump was the most common site for single bite wounds in both male and female badgers; no single bite wounds were found in either sex in either the ‘body’ nor ‘inguinal’ areas. Multiple wounding was common in both genders; 55% male, 47% female.

Badgers with multiple wounds (33/66, 50%) had these lesions divided into the specific body sites and combined for analysis with the single lesions described above (Figure 5.8). The rump was the most common site for wounds to occur in both sexes, 88% of males and 68% of females had at least one wound at this site. Although no significant difference in the site of wounding was found between the sexes, female badgers were more likely to have wounds to the head and neck, with 84% of animals having at least one wound in this site compared to 71% of males.

Figure 5.7 Number of badgers with a single bite wound at each body site and those with bite wounds at 'multiple' sites

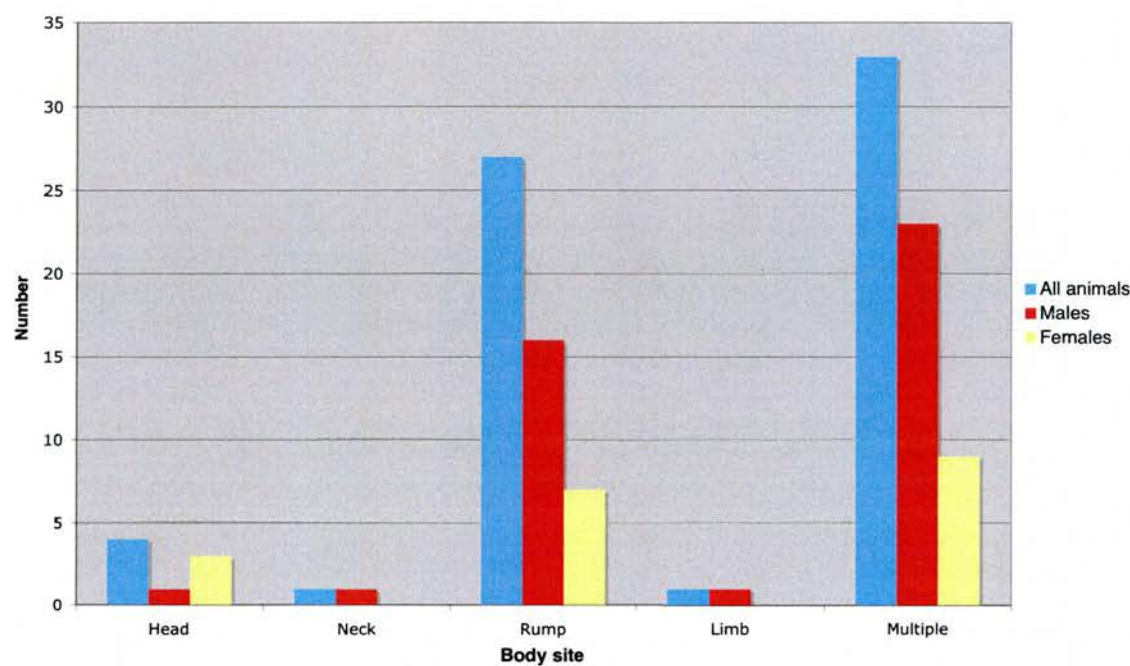
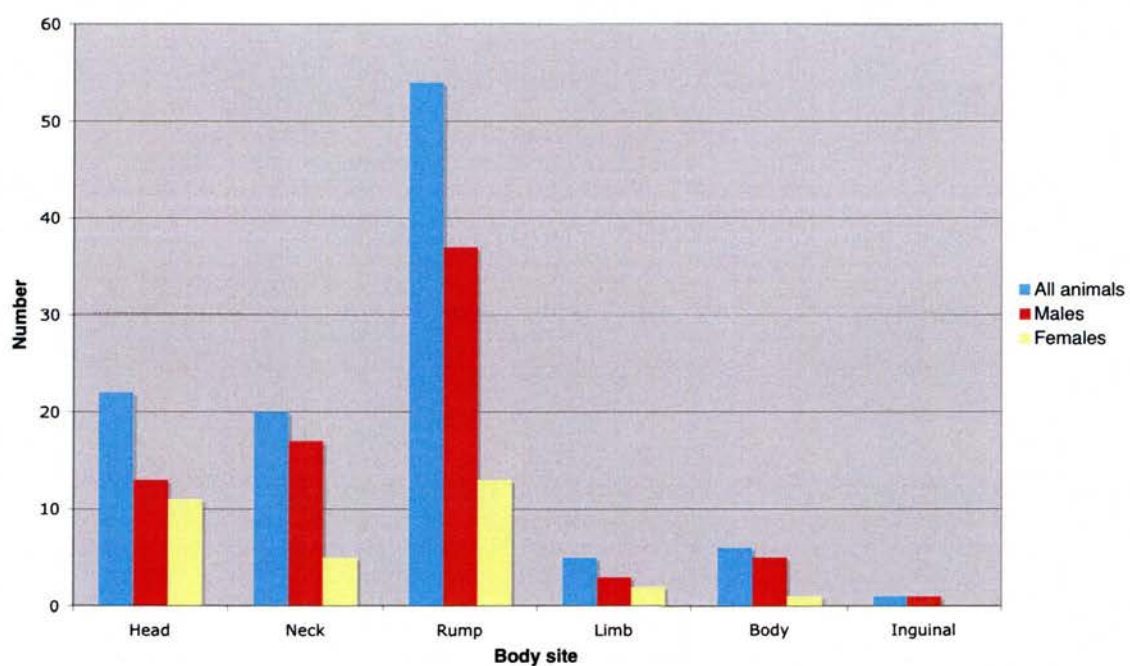


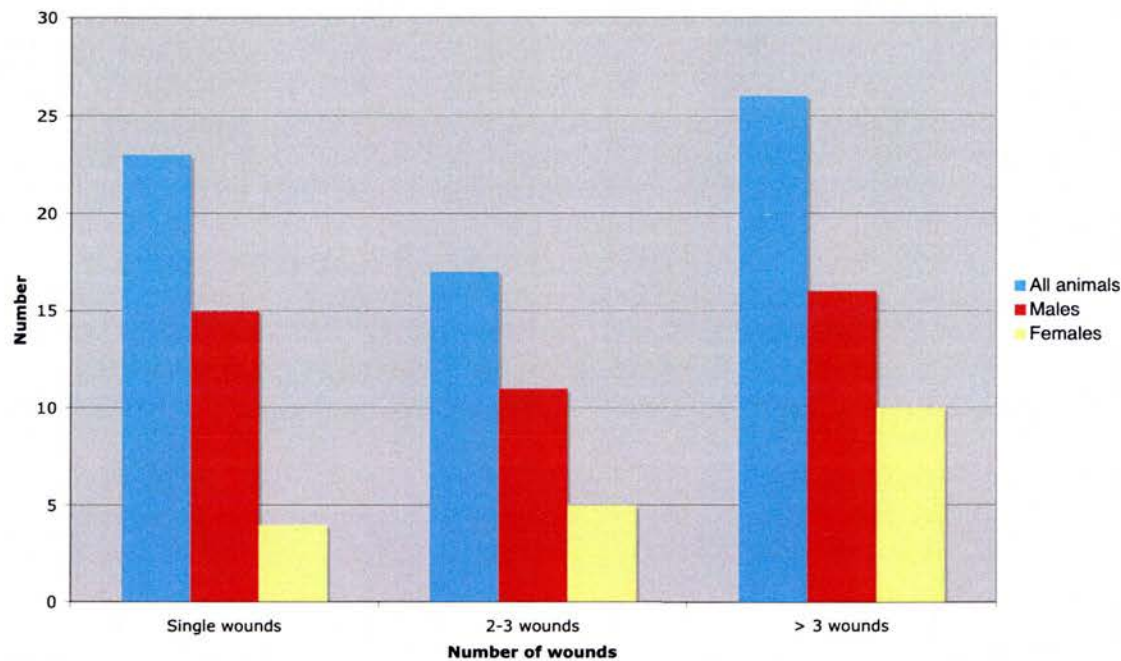
Figure 5.8 Site of all bite wounds in 66 badgers



5.3.10 Number of wounds

The number of wounds occurring at each wound site is illustrated in Figure 5.9. Male badgers more commonly had single bite wounds (36%) than females (21%), whereas multiple wounds (>3) were more commonly found in females (53%) than males (38%), however no significant difference in the number of wounds between the sexes was found.

Figure 5.9 Number of bite wounds occurring in male and female badgers



The number of wounds at each body site is illustrated in Figure 5.10. Rump wounds were significantly more likely to be single wounds ($P < 0.001$) than wounds at other sites.

5.3.11 Chronicity of bite wounds

Wounds were described as ‘fresh’, ‘old’, or ‘scar’ as previously defined in Appendix 1.1.7. The majority of bite wounds were either fresh or old, with few scars (Figure 5.11). Those lesions in the mixed category (12/63; 19%) comprised both fresh and old bite wounds in the same badger suggesting repeated confrontations and fighting.

Figure 5.10 Number of bite wounds at each body site

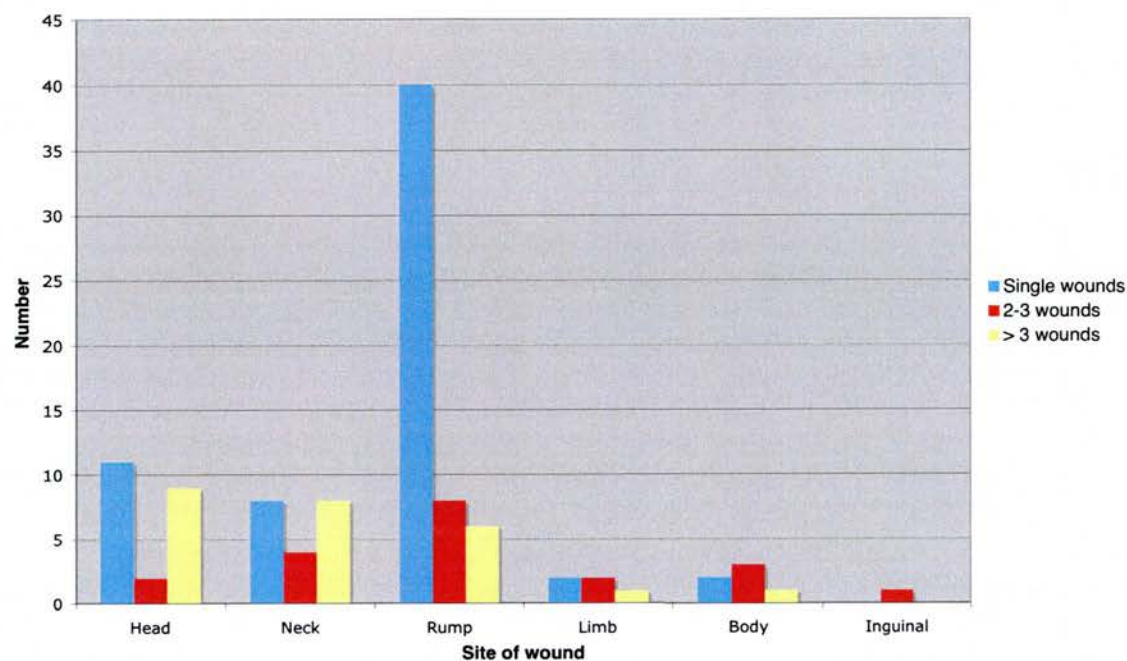
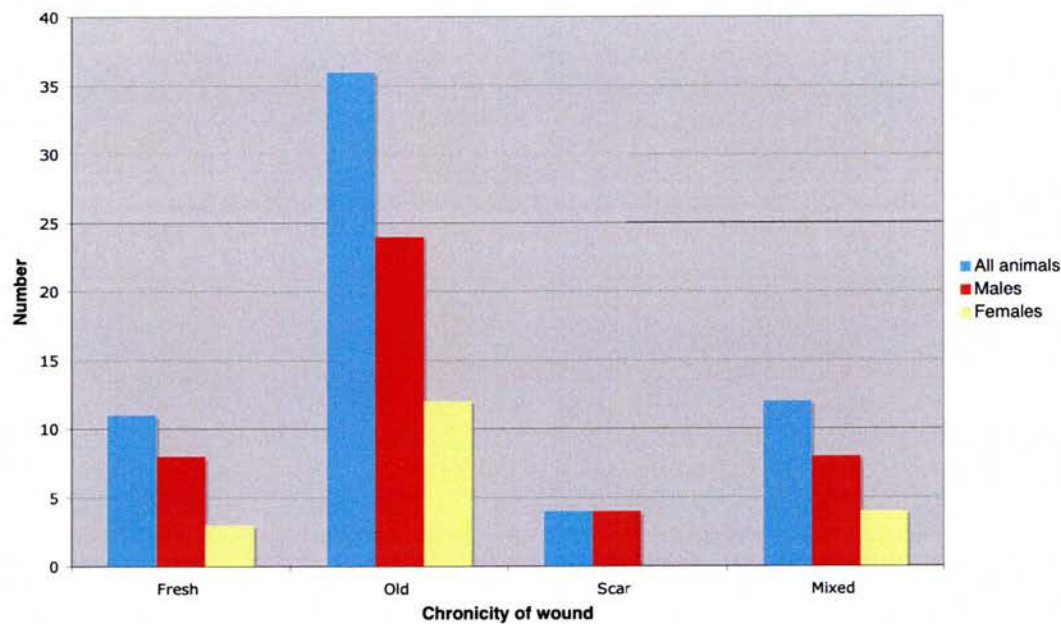


Figure 5.11 Chronicity of bite wounds including 'mixed wounds'



The mixed wounds were allocated to specific wound age categories (Figure 5.12) using the classification previously described. Old wounds were the most common wound type in both male and female badgers. There was no significant difference in chronicity of bite wounds between the genders.

When the chronicity of bite wounds was compared to the body site (Figure 5.13) there was no significant difference in chronicity between sites. The relatively small number of bite wounds to limbs were always found to be fresh.

Figure 5.12 Chronicity of all bite wounds

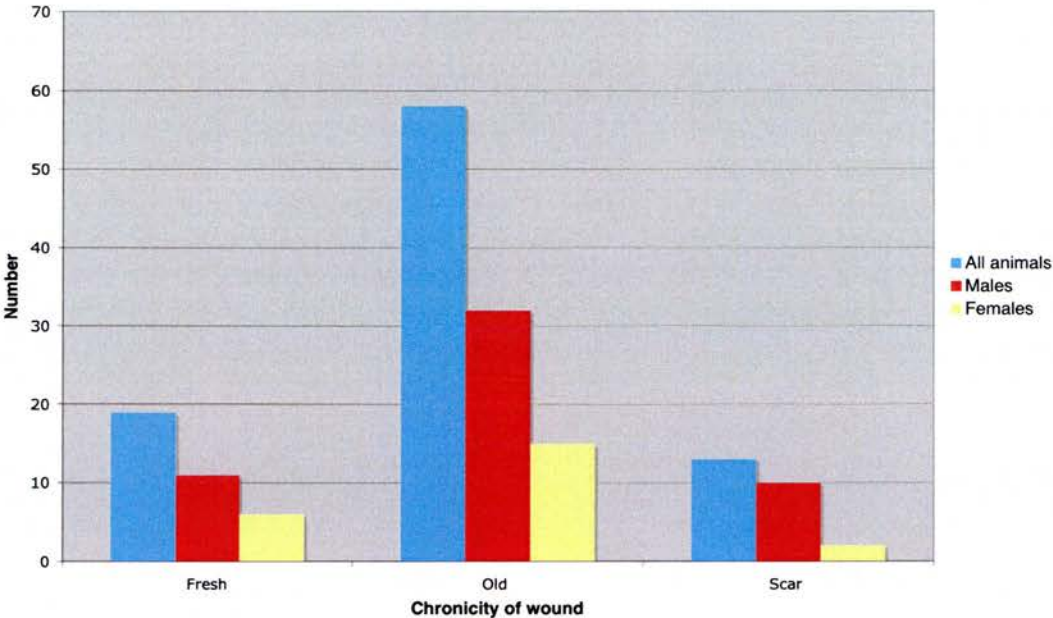
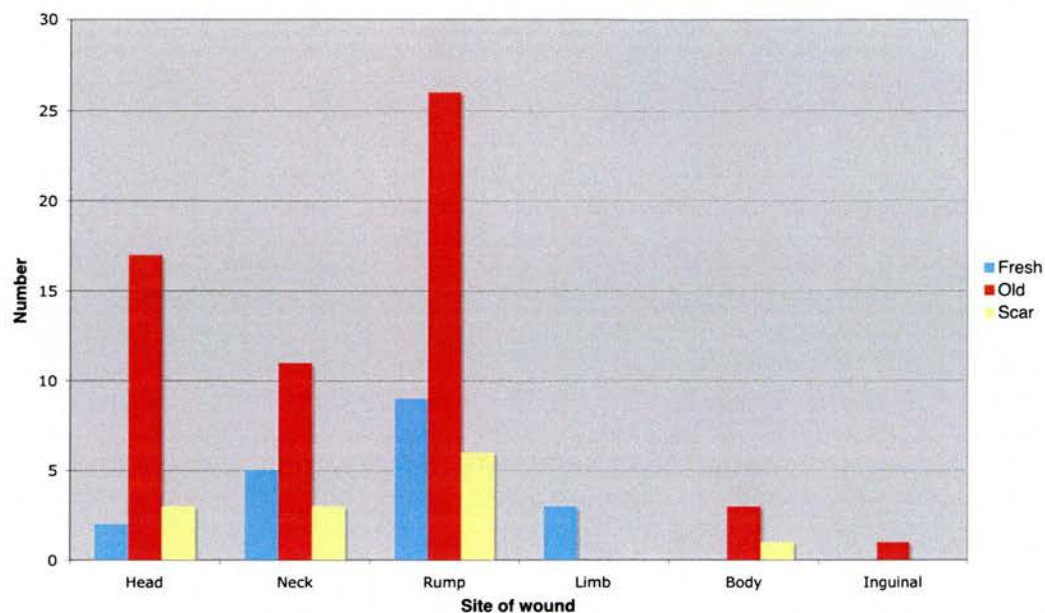


Figure 5.13 Chronicity of wounds occurring at each body site



5.3.12 Wound size

Wound size was described as ‘puncture’, ‘gash’ or ‘gaping’, several badgers (30/62, 48.8%) had multiple wounds of ‘varying sizes’ (Figure 5.14) and these were subdivided into specific categories (Figure 5.15). There were few ‘puncture’ wounds with most bite wounds classified as ‘gash’ or ‘gaping’. There was no significant difference in wound size between the sexes although females tended to have more puncture wounds.

The size of wound was considered in relation to the body site in which each was found (Figure 5.16). Puncture wounds occurred significantly more commonly on the neck ($P < 0.001$) and less commonly on the rump ($P < 0.001$). Wounds to the limb, body and inguinal areas were all punctures.

Figure 5.14 Size of bite wounds including animal with wounds of ‘varying sizes’

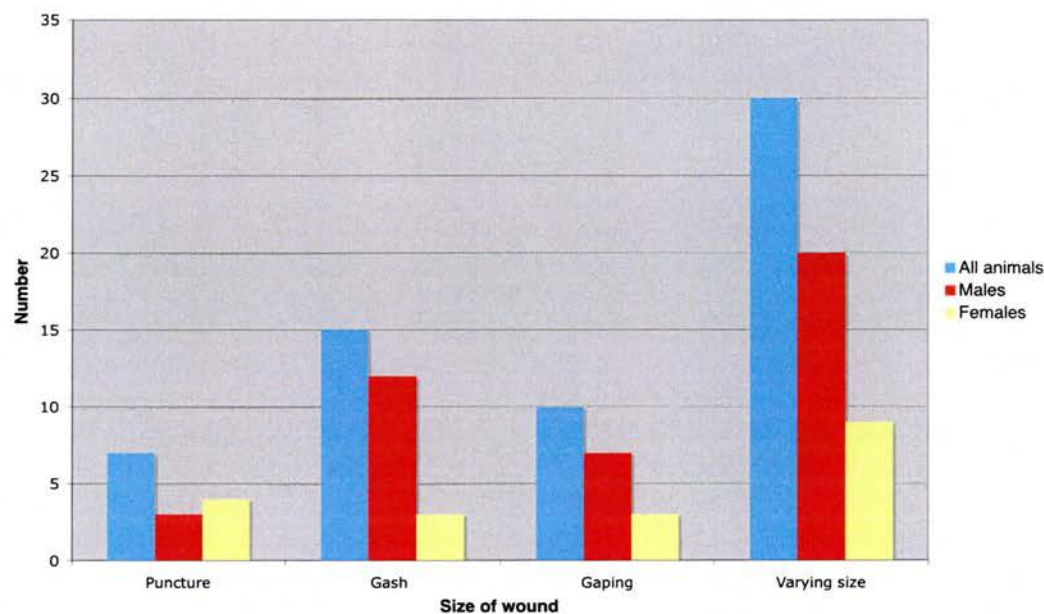


Figure 5.15 Size of all bite wounds

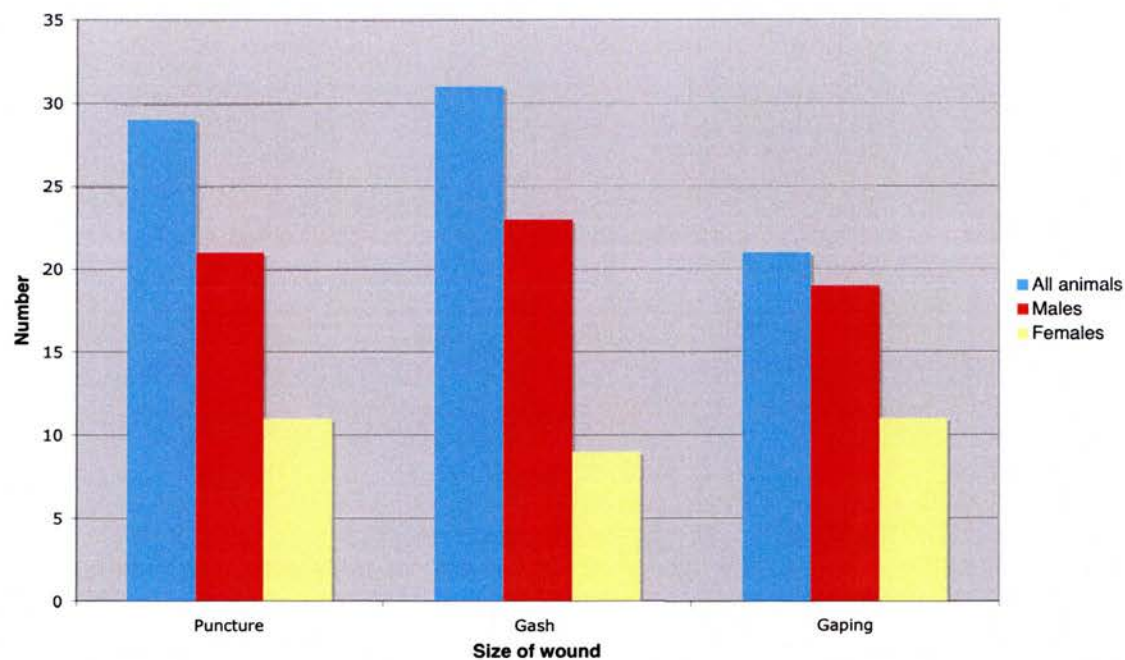
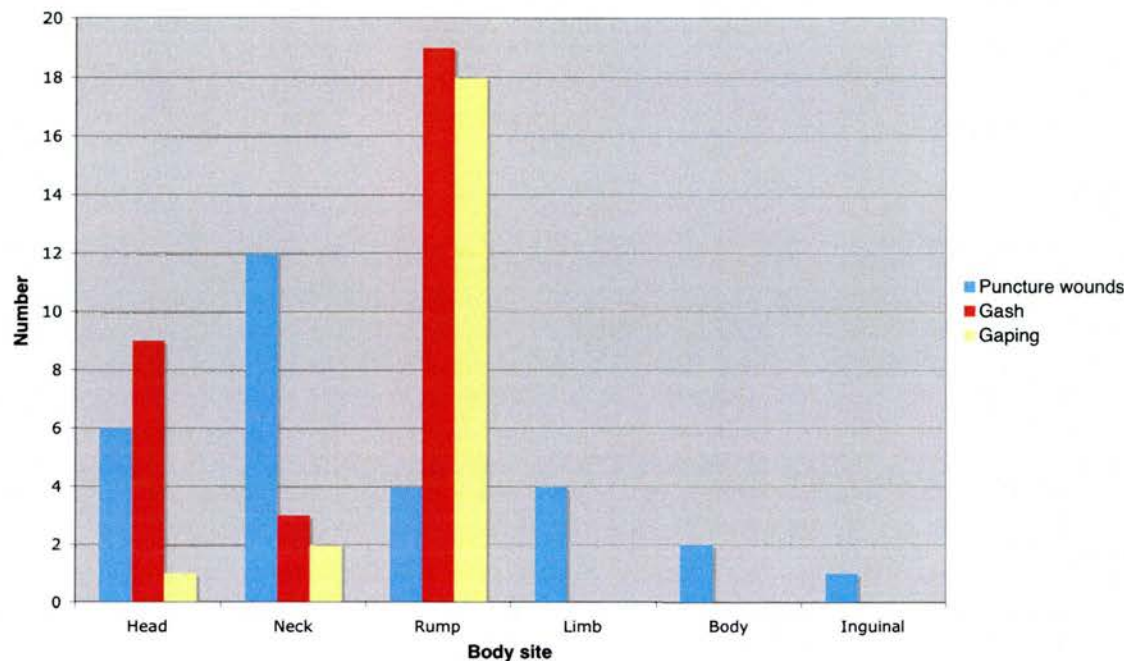


Figure 5.16 Size of wounds at each body site



5.3.13 Bacteriology

Swabs from open bite wounds were collected from 10 badgers from February 2004 onwards, swabs from two animals yielded *M. bovis*. One of these badgers also tested positive for *M. bovis* infection using a single indirect ‘Brock’ ELISA test (Table 5.3). The presence of *M. bovis* infection in the study badgers is discussed Chapter 6.

Table 5.3 Wound details of animals testing positive for *M. bovis* infection

Case number	Wound swab	Serology	Sex	Condition	Outcome
EM60	No wounds	Positive	M	Poor	Euthanased
EM61	Positive, spoligotype 11	Positive	M	Poor	Died
EM65	Positive, spoligotype 9	Negative	M	Poor	Euthanased
EM82	No wounds	Positive	F	Poor	Euthanased

It was not possible to take wound swabs for general bacteriology and sensitivity from the animals in the study population. Instead a short series of swabs from four wounded badgers was carried out in 2009-10 (Table 5.4).

Table 5.4 Results of bacteriology and sensitivity cultures from badger wound swabs 2009/10

Bacteria cultured from wounds in four badgers	Sensitivity pattern							
	Neomycin	Amox/Clav.	Cephalexin	Novobiocin	Tylocin	Ampicillin	Penicillin	Tetracycline
<i>Proteus</i> with a few coliforms	S	S	S	S	S	S	S	S
<i>Streptococcus dysgalactiae equisimilis</i>	R	S	S	S	S	S	S	R
<i>Proteus</i> species	S	S	S	S	S	S	S	S
<i>Staphylococcus aureus</i>								
<i>Streptococcus dysgalactiae equisimilis</i>	R	S	S	S	S	S	S	R

5.3.14 Plasma globulin concentrations in association with bite wounds

Plasma globulin concentrations were recorded in a total of 49 badgers, 31 of which had evidence of bite wounds. The mean serum globulin of badgers with bite wounds (Table 5.5) was higher than those without bite wounds but this difference was not statistically significant.

Table 5.5 Plasma globulin concentrations in adult badgers with and without bite wounds

Badger bite wound status	Mean plasma globulin g/L (SD)
Badgers with bite wounds (n=31)	49.8 (5.63)
Badgers without bite wounds (n=18)	46.8 (7.97)

5.3.15 Clinical findings associated with bite wounds

Clinical comments associated specifically with wounding were documented on some record forms and illustrate a range of notable clinical and complicating factors associated with bite wounds in badgers (Table 5.6).

Table 5.6 Clinical comments associated with bite wounds

Examples of clinical comments associated with bite wounds in adult badgers
All wounds clean and granulating well
Bite wounds chronic and fly blown
Flap on right ear needs to be removed
Massive chronic territorial rump wound, very infected
Massive tissue loss on rump infested with maggots
Myiasis of rump wound
No pinna, ears previously bitten off
Perineal myiasis associated with rump wound
Severe territorial wounds with damage to skeletal structures at the tail base
Vast numbers of penetrating grass seeds
Wounds on foot down to bones of digits

Wounds were usually deep, extending full thickness through the dermis and into the subcutaneous tissues, though some wounds extended further to the underlying skeletal structures including the bones of the digits and coccygeal vertebrae. Rump wounds were frequently very large extending over the whole dorsal pelvic area (Figures 5.17 and 5.18). Although wounds to the head were typically smaller they frequently included tears to ears that had left the badgers without pinnae or required surgery to debride damaged tissue. Wounds were sometimes complicated by myiasis, and organic debris including hay, straw and grass awns was also frequently adhered to the wound surface (Figure 5.17).

Figure 5.17 Rump bite wound at admission



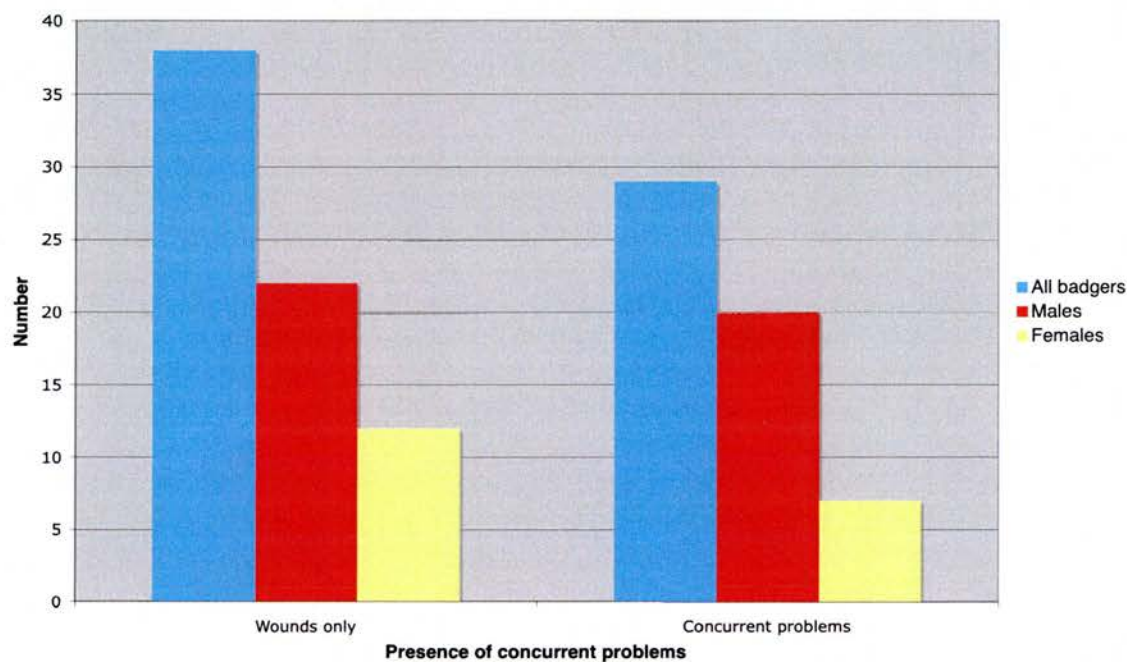
Figure 5.18 Rump bite wound after initial cleaning and debridement



5.3.16 Concurrent problems associated with bite wounds

Following clinical assessment badgers were categorised as having bite wounds only or as having bite wounds in addition to other clinical problems (Figure 5.19). There was no significant difference in these data between the genders.

Figure 5.19 Occurrence of bite wounds only compared to bite wounds with concurrent clinical problems in adult badgers



5.3.17 Treatment of bite wounds

Twenty-two badgers (33%) with wounds were euthanased within 24 hours of admission and examination, the remainder received treatment appropriate to the severity of the wounds (Figure 5.20). Eight badgers required no treatment. Thirty-seven badgers (55%) received some form of intervention; topical cleaning and wound care only (4%), cleaning with the addition of systemic medication (45%) or minor surgical debridement followed by topical and systemic treatment (6%). Where systemic medication was used the choice of treatment was determined by the case veterinary surgeon and was influenced by concurrent problems in some cases (Table 5.7).

Figure 5.20 Treatment of badgers with bite wounds in the first 24 hours following admission

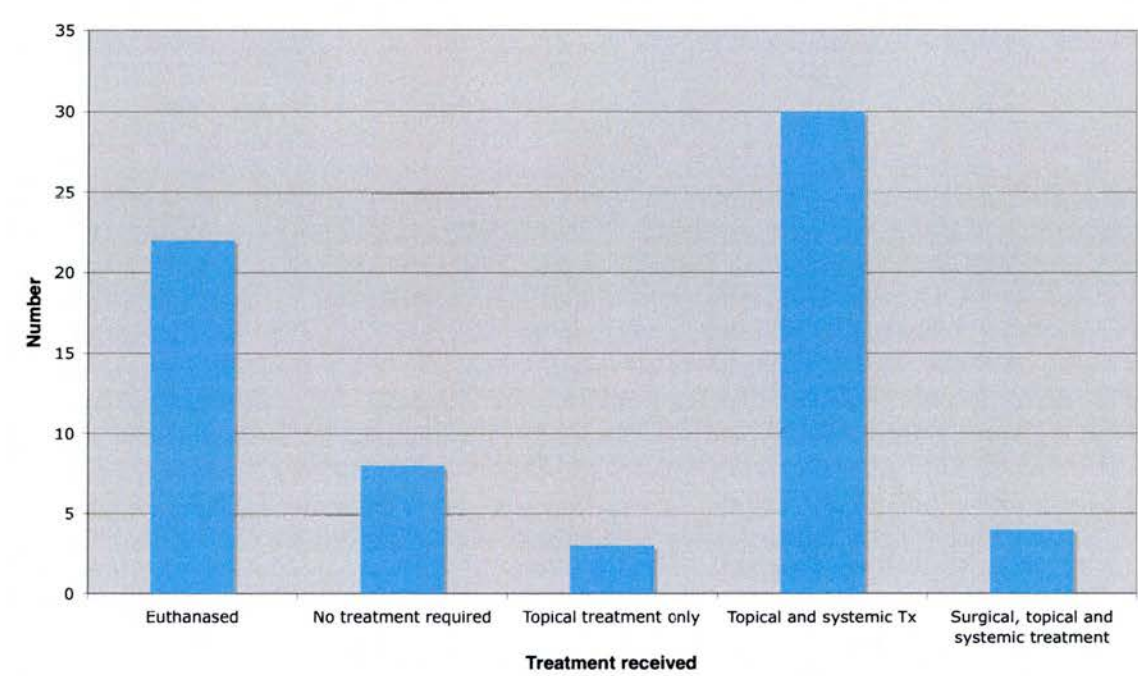


Table 5.7 Systemic medical management of bite wounds

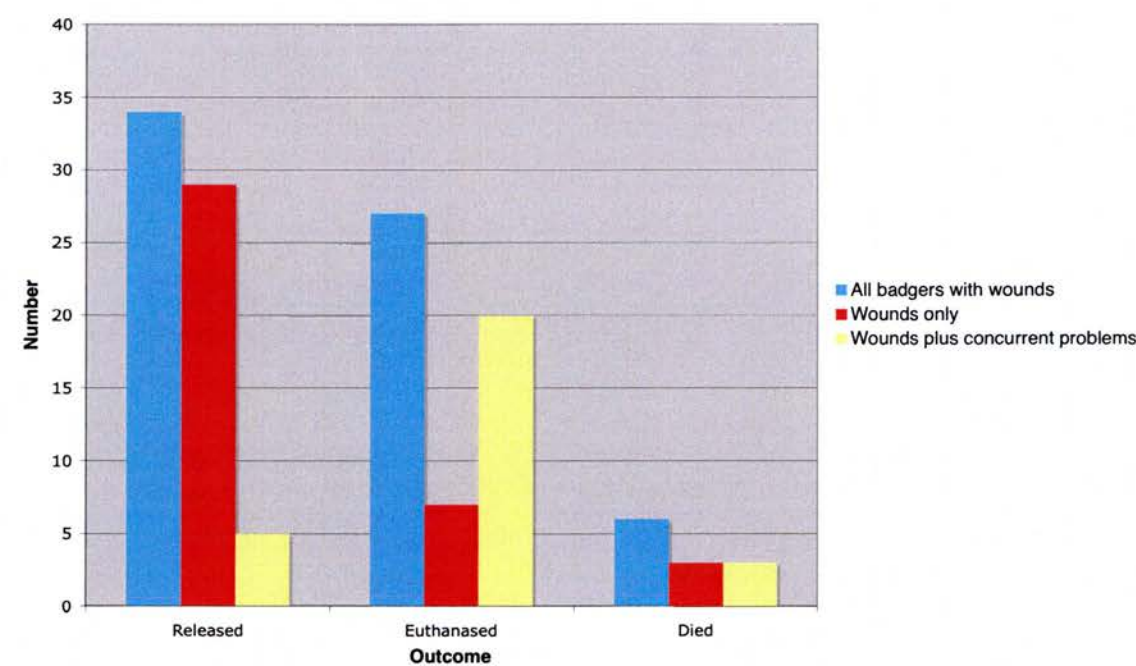
Type of systemic medical treatment	Number receiving this treatment (n= 34)	Drugs used (number treated)
Antibacterial drugs	34	Amoxicillin (<i>Amoxycare LA injection</i> [™] ; Animalcare Ltd., York) (10/30; 29%) Amoxicillin and clavulanic acid (<i>Noroclav injection</i> [™] ; Norbrook Laboratories Ltd., Newry) (23/34; 68%) Clindamycin (<i>Antirobe Capsules</i> [™] ; Pfizer Ltd., Sandwich) (1/34; 3%)
Anti inflammatory drugs	19	Dexamethasone (<i>Dexadreson</i> [™] ; Intervet UK Ltd.) (1/19; 5.3%) Meloxicam (<i>Metacam</i> [™] 5% solution for injection for dogs and cats; Boehringer Ingelheim Ltd., Bracknell) (18/19; 94.7%)
Fluid therapy	2	Hartmann's solution (<i>Aquapharm 11 solution for infusion</i> ; Animalcare Ltd., York) (2/2)

5.3.18 Outcomes for badgers with bite wounds

The three possible outcomes for the badgers brought into captivity were; successful return to the wild, euthanasia during the treatment and rehabilitation process, unforeseen death in captivity. Badgers with wounds and the presence of concurrent clinical problems were significantly more likely to be euthanased or die ($P < 0.001$) than those with only bite wounds. Release rates (Figure 5.21) were significantly higher for badgers with bite wounds only compared to those badgers with bite wounds and concurrent problems ($P < 0.001$). Badgers with both bite wounds and concurrent problems were almost three times more likely to be euthanased ($P < 0.001$) than those badgers with bite wounds only. Only five of 30 badgers with bite wounds and concurrent problems were returned to the wild.

Where badgers with bite wounds only were successfully treated and released they were kept in captivity for between 6 and 48 days with a mean duration of 22 (SD 11.7) days.

Figure 5.21 Outcomes for badgers with bite wounds and with concurrent clinical problems



5.4 Discussion

The finding that 55% of badgers in the present study had bite wounds is much higher than other studies, with values of only 6% in post-mortem examination surveys of culled and badgers involved in RTAs (Gallagher and Nelson, 1979), and 7.5% in free-living badgers (Delahay *et al.*, 2006b). The prevalence of bite wounds has been shown by some researchers to be related to increased population density and greater territorial conflict (Macdonald *et al.*, 2004b), whilst others have found the incidence of bite wounds to be unrelated to study area or population density (Delahay *et al.*, 2006b). In otters the prevalence of conspecific bite wounds increased as population density increased (Simpson *et al.*, 2006). Since the badgers in the present study came from a wide geographical area with varying population densities, the high incidence of bite wounds cannot be explained by local social conflicts alone and suggests bite wounds are a major reason for admission of casualties rather than just an incidental finding. Bite wounds were the main reason for animals being presented by finders in 18% of all badger casualties. Bite wounds were also one of the most common reasons for badger admissions to the RSPCA's West Hatch Wildlife Hospital (Cousquer, 2002).

Bite wounds were recorded in badger casualties in every month of the year except December, with a distinct seasonal peak during the spring in March and smaller peaks in August and September in females and males, respectively. Studies of free-ranging badgers found bite wounds throughout the year with seasonal variation as described below (Cresswell *et al.*, 1992; Delahay *et al.*, 2006b). Veterinary admissions of badgers with bite wounds to a wildlife hospital over a two year period found no admissions in November or December (Cousquer, 2002) however, admissions may be influenced not just by the seasonality of wounding but also as a result of contact between badgers and people, which will be less in the winter months.

Although some authors have found no seasonal trend in bite wounds in badgers (Macdonald *et al.*, 2004b), most authors have reported seasonal variation similar to that reported in the present study, which correlates with peak breeding activity (Cresswell *et al.*, 1992). Most badger mating activity occurs post partum in January

to March and aggression at this time is thought to correlate with territorial behaviour between male animals and aggression over cubs within the sett between breeding sows (Cresswell *et al.*, 1992). A further increase in the incidence of wounding is associated with the second period of breeding activity in autumn. Testosterone concentrations follow a similar biphasic seasonal trend in male animals, although no direct correlation between these levels in individuals and incidence of bite wounds has been shown (Buesching *et al.*, 2009). The seasonal variation in bite wounds reported in the present study of rehabilitated badgers showed similar trends to a field study where wounds were highest in male badgers during February and March, with a less distinct peak in September and highest in females during April and November-December (Cresswell *et al.*, 1992). In another study a peak in bite wounds occurred between December and February (Delahay *et al.*, 2006b). A post-mortem survey found a peak in bite wounds in March (Gallagher and Nelson, 1979). Cresswell *et al.* (1992) found the lowest prevalence of bite wounds in July. The number of badgers with bite wounds fell during the summer months in parallel with the declining number of casualties, although a slight rise was seen in June corresponding with an increase in the number of road accidents seen at this time of year (Figure 3.3).

Badgers were presented for a wide variety of reasons and were found in many different locations. Although ‘thin’ badgers and those found ‘in the wrong place’ had more bite wounds than those found at the roadside, bite wounds occurred in all presentation categories and in some badgers were the sole reason for presentation. This supports our knowledge that bite wounds result from badger social interaction and are a common finding in the general badger population (Kruuk, 1989; Cresswell *et al.*, 1992; Neal and Cheeseman, 1996; Delahay *et al.*, 2006b) rather than being limited to specific groups of casualty animals. Bite wounds were however significantly more common in badgers found in buildings than in other locations, and were especially common in those badgers found in farm buildings. Individual badgers seeking refuge away from the sett following territorial disputes may explain this finding, with farm and domestic buildings providing suitable hiding places. Badgers have been shown to use domestic and farm buildings on a regular basis for both refuge and foraging (Cheeseman and Mallinson, 1981; Sleeman and Mulcahy, 1993; Garnett *et al.*, 2002; Roper *et al.*, 2003; Pavlacik *et al.*, 2004; Ward *et al.*,

2008; Sleeman *et al.*, 2008; Tolhurst *et al.*, 2009), with male badgers frequenting farm buildings more commonly than females (Tolhurst *et al.*, 2009).

The putative association between the frequent use of buildings and *M. bovis* prevalence in badgers (Cheeseman and Mallinson, 1981) may occur either because bite wounds are one route of transmission of *M. bovis* infection in badgers (Gallagher *et al.*, 1976; Gallagher and Nelson, 1979; Clifton-Hadley *et al.*, 1993; Gavier-Widen *et al.*, 2001; Jenkins *et al.*, 2008) or because *M. bovis* infection may result in debilitation and an increased likelihood of bite wounds. The zoonotic risk of *M. bovis* from badgers when treating bite wounds is discussed in Chapter 6.

The present study population consisted of equal gender numbers but male badgers were significantly (2.3 times) more likely to have bite wounds than females. Several studies of free-living populations have also found bite wounds more commonly in male badgers (Cresswell *et al.*, 1992; Macdonald *et al.*, 2004b; Delahay *et al.*, 2006b) reflecting increased social and territorial disputes between males. In a previous study (Delahay *et al.*, 2006b) the incidence of bite wounds in male badgers was 1.5 times that in females although there was some variation between the study sites. Conversely, the only study of badgers with bite wounds presented for veterinary treatment found an equal sex ratio (Cousquer, 2002).

Slightly more males than females had multiple wounds and this concurred with findings in other studies (Cresswell *et al.*, 1992; Delahay *et al.*, 2006b). Male badgers have been found to suffer not only from more bite wounds but also more severe wounds than females (Cresswell *et al.*, 1992; Macdonald *et al.*, 2004b) as discussed further below. Although male badgers are bitten more frequently than females, the consequences on breeding activity can be significant in sows where higher bite wound scores have been associated with poorer blastocyst development and reduced fertility (Cresswell *et al.*, 1992). Tuberculosis lesions associated with bite wounds however occur mostly in males (Clifton-Hadley *et al.*, 1993). In female otters the incidence of bite wounds increased at a greater rate than in males when population density, and the overall incidence of bite wounds, increased (Simpson *et al.*, 2006).

Bite wounds in the present study were more common in older badgers as defined by tooth wear grades, but unlike other studies (Macdonald *et al.*, 2004b) the prevalence was not significantly different between age groups. The present study population consisted predominantly of adult badgers and only one of the five independent juvenile animals had wounds. Other studies have shown a higher incidence of wounds in adults than cubs (Delahay *et al.*, 2006b).

Bites wounds occurred in badgers across the full range of condition scores; 36% of badgers with bite wounds were in poor condition while 30% were in good condition, contrary to previous reports where badgers with bite wounds were in poorer body condition, although the results were variable according to study site and time of year (Delahay *et al.* 2006b).

The mean weight of badgers with bite wounds in the present study was significantly less than badgers without evidence of bite wounds. Cresswell *et al.* (1992) found no correlation between the incidence of bite wounds in male badgers and body weight, contrary to the findings of Macdonald *et al.* (2004b) who reported that heavier animals had more bite wounds. The positive relationship between bite wounds and body weight was explained by increased reproductive activity during the breeding season in heavier dominant male badgers compared to their lighter counterparts; the seasonal variation in body weight in these animals was however unknown (Macdonald *et al.*, 2004b). The mean weight of badgers in the study group may have been influenced more by bite wounds than in the general badger population because of the bias of the former population towards debilitated animals.

Bite wounds were seen in the rump, head and neck areas in the present study as previously described in other studies of wild badgers (Gallagher and Nelson, 1979; Cresswell *et al.*, 1992) and those presented for veterinary care (Lewis, 1997b; Cousquer, 2002). The rump area was the most common site affected consistent with other authors' findings (Delahay *et al.*, 2006b). Bite wounds to the limbs were uncommon occurring in only 8% of cases. Bite wounds are potential routes for both monostotic and polyostotic osteomyelitis in badgers as discussed in Chapter 4. The finding that 50% of the badgers in the present study had multiple wounds was much

higher than 11% reported by Delahay *et al.* (2006b) however, that study considered only 'fresh' bite wounds. More male than female badgers were found to have multiple wounds which concurred with other studies (Cresswell *et al.*, 1992; Delahay *et al.*, 2006b).

The gender bias of bite wound distribution, as described above, was also consistent with the findings of other studies whereby wounds were more common on the rump of males (Macdonald *et al.*, 2004b; Delahay *et al.*, 2006b) and on the head of females (Delahay *et al.*, 2006b). Delahay *et al.* (2006b) suggested that wounds occurred most commonly on the rump in males as they were retreating from aggressors, whilst in females the head was more vulnerable when defending cubs or the head and neck areas are bitten during mating. Macdonald *et al.* (2004b) suggested the fighting style in male animals resulted in the more aggressive rump bite wounds whereas in female animals more demonstrative mouthing at each other may be the norm. Bite wounds to the chest causing death (Gallagher and Nelson, 1979), were not seen in the present study.

Several studies have attempted to classify the 'severity' of bite wounds in badgers (Cresswell *et al.*, 1992; Macdonald *et al.*, 2004b; Delahay *et al.*, 2006b). In this study three factors were considered; number, chronicity (age) and size of the bite wounds. The number of bite wounds occurring in the study badgers has been described above. Different ages of bite wounds were found at most of the body sites with 'old' bite wounds predominating. The bite wounds to limbs were all 'fresh', suggesting that bites to limbs result in more rapid debilitation and earlier veterinary admission than wounds to other sites. In common with the findings of another study (Macdonald *et al.*, 2004b) scars from wounds occurred more commonly in males than females, conversely Gallagher and Nelson (1979) reported scars occurring equally in both sexes. Approximately one fifth of badgers had at different stages of healing indicating that biting occurs commonly during badger interactions.

The size of wound varied between body sites; rump bite wounds were significantly more likely to be gashes or gaping wounds and wounds to the neck significantly more likely to be punctures. This correlates with observations of fighting styles

suggested by others (Macdonald *et al.*, 2004b; Delahay *et al.*; 2006b) and described above. Both male and female badgers in the present study suffered bite wounds of several sizes and the overall pattern was no more severe in males as has been suggested by others (Cresswell *et al.*, 1992; Macdonald *et al.*, 2004b). However, the lack of sex difference may, in part result from the bias in the population of casualty animals, which may naturally select badgers that have more severe bite wounds in both genders.

Culture of bite wound swabs yielded *M. bovis* infection in two out of 10 samples. *M. bovis* has previously been identified from bite wounds in several studies (Gallagher *et al.*, 1976; Gallagher and Nelson, 1979; Clifton-Hadley *et al.*, 1993; Delahay *et al.*, 2006b; Jenkins *et al.*, 2008). Although the present sample size of animals was small, nonetheless the prevalence was higher than other studies that cultured *M. bovis* from only 6% of 47 badgers (Clifton-Hadley *et al.*, 1993). Three out of four badgers with evidence of tuberculosis were males, which is consistent with a greater prevalence of infection in male badgers (Clifton-Hadley *et al.*, 1993).

Molecular techniques, including spoligotyping, have been described for identification of *M. bovis* strains from bite wound swabs (Harris, 2006). *M. bovis* spoligotypes 9 and 11 found in the present study corresponded with those found in cattle in the south west of England (Bourne *et al.*, 2007a).

Tuberculosis associated with bite wounds occurred in up to 14.1% of infected badgers and was considered an aggressive and acute form of the disease (Gallagher and Nelson, 1979). The survival time of badgers with tuberculous bite wounds was on average a quarter that of animals with tuberculous lesions originating at other sites (Clifton-Hadley *et al.*, 1993). Post-mortem studies of tuberculous badgers with bite wounds showed a higher prevalence and a different distribution of visible lesions to that occurring from aerosol infection (Jenkins *et al.*, 2007). Haematogenous spread from a focus of infection such as an infected wound may affect several systemic organs including the liver, kidney and spleen (Gallagher *et al.*, 1976; Clifton-Hadley *et al.*, 1993; Gallagher *et al.*, 1998; Gavier-Widen *et al.*, 2001; Jenkins *et al.*, 2008). The two badgers with bite wounds and clinical or serological evidence of *M. bovis*

infection in the present study were in poor condition indicating the negative clinical effects of the disease, however specific organ damage was not confirmed on biochemical tests, as will be described later (Table 6.1).

The presence of *M. bovis* infection in bite wounds in badgers presents a real zoonotic risk for rehabilitation workers and must be duly addressed by veterinarians and rehabilitators. Protective gloves and clothing must be worn when treating badgers with bite wounds to reduce the risk of infection. There is also a potential risk to livestock and other animals through release of infected badgers. None of the four animals testing positive for *M. bovis* infection in the present study was released; three were euthanased (including one with bite wounds) and one animal (with bite wounds) died within 24 hours. The issues associated with *M. bovis* infection in the study population are discussed in more detail in Chapter 6.

There are limited studies regarding other types of bacteria contaminating wounds and no reported antibacterial sensitivity studies for cost reasons (Cousquer, 2002). The small sample of bite wound swabs submitted for bacteriology in this study yielded *Proteus*, coliforms, *Staphylococcus aureus* and *Streptococcus dysgalactiae equisimilis*, consistent with other studies, which reported mixed infections of *Staphylococcus pyogenes*, beta-haemolytic streptococci and coliforms (Gallagher and Nelson, 1979).

Streptococci are frequently isolated from bite wounds in foxes (Brash, 2003). In the Eurasian otter where bite wounds may result from other otters, dogs and American mink (*Mustela vison*) *Streptococcus* species were predominant, commonly *Streptococcus dysgalactiae equisimilis* (10/25 cases), with mixed infections including *Staphylococcus* species, *Aeromonas hydrophila* and *Corynebacterium ulcerans* (Simpson, 2006). In domestic dogs soft tissue infections, including those from bites and other penetrating injuries, are most commonly infected with *Staphylococcus* spp. although *E. coli*, *Bacteroides* and *Clostridium* spp. also frequently contaminate wounds involving the gastrointestinal tract, whilst in cats *Pasteurella* spp. are the most common isolate (Remedios, 1999).

No significant antibacterial resistance was observed in the small number of cultures reported suggesting the antibacterial drugs used were appropriate.

Plasma globulin concentrations were higher in those badgers with bite wounds but not significantly different to those animals without bite wounds. Globulin concentrations increase in the presence of infectious or inflammatory lesions such as bite wounds as a result of B-lymphocyte stimulation as discussed in Chapter 4. However, it is possible that badgers without evidence of bite wounds had other chronic bacterial infections, not all of which could be detected on clinical examination alone. The lack of necropsy examinations further restricts the interpretation of plasma globulin concentrations.

Almost half of the badgers with bite wounds also had other clinical conditions and it was not possible to determine whether the bite wounds were the primary condition or a secondary consequence of debility or disease. Pre-existing bite wounds were observed in badgers acutely injured in road accidents where there was no indication that the wounds had contributed to this occurrence; indeed bite wounds were less common in roadside badgers than those found elsewhere. Conversely chronically injured or diseased badgers, for example those with healing fractures from a previous RTA, had recent bite wounds and these badgers were often found in buildings. This sequence of events suggests bite wounds following injury as debilitated badgers are subjected to increased aggressive territorial behaviour and are driven from the sett area and seek refuge in farm and domestic buildings. The presence of concurrent injuries emphasises the need not only to triage (Cousquer, 2002) but also to thoroughly examine the badgers for signs of other injury or disease.

The presence of concurrent problems significantly influenced the likelihood of successful release of an adult badger casualty, whereby animals with bite wounds and concurrent injuries were four times more likely to be euthanased than animals with bite wounds alone. The decision to euthanase or treat a badger casualty was one of veterinary judgement as discussed in Chapters 4 and 7. Badgers with concurrent problems were also more likely to die in captivity than those with only bite wounds,

which supports the assessment and decision-making employed, where animal welfare was the major consideration.

Most bite wounds required only topical cleaning with saline or dilute chlorhexidine (Mullineaux, 2003a; Appendix 2.7) with most wound debridement achieved using gauze swabs. Four animals required minor surgery of the bite wounds; in three cases this related to the removal or suturing of pinnae and in the fourth removal of a large area of necrotic tissue from a rump wound. More involved surgical procedures such as transpositional cutaneous flaps were not considered necessary and have not previously been successful when employed in badger bite wounds (Keeble, 1999). Alternative techniques requiring topical wound dressings changes every 3-4 days (Cousquer, 2002) have practical and cost implications and were not considered necessary in this study.

Most of the badgers requiring topical medical treatment of wounds also received broad-spectrum antibacterial drugs in the early stages as previously recommended (Cousquer, 2002; Mullineaux, 2003a). The choice of antibiotic was often influenced by the presence of concurrent medical problems. Bacteriology and sensitivity studies prior to antibiotic selection were not employed for cost reasons (Cousquer, 2002) however from the small number of swabs subsequently cultured, and clinical responses to treatment, the choices of antibacterial used appear to be appropriate.

Two thirds of the badgers treated with antibiotics also received the non-steroidal anti-inflammatory drug (NSAID) meloxicam. Cleaning and debriding of wounds was considered to be a painful procedure requiring suitable analgesia. NSAIDs are frequently used in companion animal veterinary practice for pre and post operative analgesia, often in combination with opioid drugs (Capner *et al.*, 1999; Slingsby and Waterman-Pearson, 2001). NSAIDs are particularly useful for wildlife casualties compared to other analgesics, such as opioid drugs, as they have a longer duration of effect (Lascelles *et al.*, 1994; Laredo *et al.*, 2004), no behavioural side effects, less cardiovascular and respiratory side effects and no regulatory control arising from potential abuse (Kerr, 2007). In dogs and cats behavioural indicators of pain include; altered demeanour and response to people, changes in posture, mobility, activity,

response to touch, attention to the painful area, vocalisation and inappetance (Holton *et al.*, 2001). Since the aim in wildlife casualty management is release based upon a return to normal behaviour and function, pain management would seem appropriate as well as in the best interests of the casualty. As some side effects have been associated with NSAIDs especially in longer-term (over 28 days) use (Innes *et al.*, 2010a, b) and there are no products licenced for use in badgers, duration of medication was limited according to clinical need. In most cases five consecutive days' medication was considered appropriate as this avoided long-term use and allowed most wounds to resolve from an acute inflamed state to one where minimal topical care was required.

Animals were kept in captivity until bite wounds had fully granulated and were beginning to scar thereby preventing further infection or trauma upon release. Badgers successfully treated for bite wounds were released after 6-48 (mean 22) days. Other authors have suggested a maximum period of 4-6 weeks for wounds to heal, after which time it is suggested that badgers should be euthanased (Cousquer, 2002), but no actual times taken for individual wounds to heal are given. Keeping badgers in captivity for protracted periods of time raises some ethical dilemmas.

The time badgers can spend in captivity without disruption to their social order and their general wellbeing is unknown although anecdotal reports (P. Kidner *pers. comm.*) suggest that animals are well accepted by their social group even after several weeks away from the sett, but there must be concern that in such a socially aggressive species too long away from the group may result in further wounding. In the wild severe bite wounds are considered common (Macdonald *et al.*, 2004b) and are said to heal rapidly without veterinary intervention (Delahay *et al.*, 2006b). Based upon such evidence it is sensible to question the need to treat animals with bite wounds especially if protracted periods in captivity are required. Reports of healing in the wild are however based only upon the personal observations of authors following sequential trapping of marked animals (Delahay *et al.*, 2006b). There are no published findings or observations as to the frequency or number of animals recovering from bite wounds or observations as to what happens to those badgers not

trapped subsequently, even though bite wounds have had fatal consequences in individual badgers (Gallagher and Nelson, 1997).

In hedgehogs more than one month in captivity prior to release increased survival probability compared to direct translocation because weight-gain in captivity limited the negative effects of weight loss upon release (Molony *et al.*, 2006). The hedgehogs were however released in their captive groups (Molony *et al.*, 2006) and did not have to deal with the potential social aggression encountered in badger groups.

The Abandonment of Animals Act, 1960 makes it an offence to abandon an animal and cause unnecessary suffering, and wildlife species should not therefore be released unless they are able to survive unaided in the wild. Veterinary surgeons also have additional responsibility for 'animals under their care' (VSA, 1966, as amended 2002), which is enforced by their regulatory bodies (RCVS, 2008). Release of badgers with bite wounds before they were fully clinically fit would contravene such legislation.

Overall 51% of badgers with bite wounds were successfully rehabilitated and released. The prognosis for badgers with bite wounds was better than for the overall study population in which 39% of badgers were eventually released, a similar finding to other studies with 31% release rates for mammals (Best, 1999; BWRC, 2000) and 39% for all casualties (Molony *et al.*, 2007). These results indicate that in comparison to other wildlife casualties, and especially in the absence of other significant injury or disease, badgers with bite wounds carry a good prognosis for release.

5.5 Summary

This study found that bite wounds are a common problem in badgers admitted to veterinary practices and reflects the high incidence of bite wounds in the free-living population. The seasonality of bite wound admissions correlates with the badger breeding seasons. Although wounds were found most commonly in badgers in buildings, especially in males, wounds were not uncommon in badgers found at the roadside.

The higher incidence of bite wounds in male badgers in the present study concurs with studies of other free-living populations, and reflects differences in social and territorial behaviour and fighting style between the genders. Bite wounds in male badgers were more common in rump area and typically single and large. Female badgers more commonly had multiple smaller wounds to the head. Bite wounds were generally old rather than fresh. Presence of bite wound scars and wounds of varying ages in individual animals suggests that wounding is a repeated occurrence in a badger's life and that wounds heal well under natural conditions.

Two bite wounds yielded *M. bovis*, which presents a zoonotic risk to those handling badgers in captivity. The bacteria cultured were similar to other omnivore species and antibacterial drugs recommended in veterinary texts are appropriate for badgers with bite wounds.

Many badgers with bite wounds had concurrent problems, which significantly impacted upon successful treatment and release. This emphasises the importance of effective triage of casualties and a thorough clinical examination. Since bite wounds in badgers are often large and obvious the presence of another more important disease or injury might easily be overlooked. The prognosis for successful release was good if only bite wounds were present, although legal responsibility and duty of care necessitate long periods in captivity in suitable rehabilitation facilities before release.

Chapter 6

Tuberculosis (*M. bovis* infection)

6.1 Introduction

M. bovis infection of free-ranging wildlife is considered to be a spill-over from domestic animal populations and may be implicated in the spread of infection to cattle throughout the world (Corner, 2006). In the UK *M. bovis* infection has been identified in many free-living mammalian species (Delahay *et al.*, 2001; Delahay *et al.*, 2007a) although few are considered to be maintenance hosts. Since badgers were first implicated in the transmission of tuberculosis to cattle in the 1970s (Muirhead *et al.*, 1974) they have been identified as maintenance hosts and are considered to be the significant reservoir of infection for cattle in the UK and Ireland (Cheeseman *et al.*, 1988; Corner, 2006; Kaneene and Pfeiffer, 2006).

Unfortunately, the implication of badgers in the spread of *M. bovis* infection to cattle adversely impacts upon badger rehabilitation and release as much for political reasons as for disease control. Although the general public are largely supportive of badgers and oppose culling as a method of controlling bTB in cattle (DEFRA, 2006; Bennett and Willis, 2007a), sections of the farming and veterinary communities would vehemently oppose all forms of badger rehabilitation if it was not carried out to rigorous guidelines. Formal guidelines for badger rehabilitation, with specific consideration of *M. bovis* infection (Mullineaux, 2003b; SWWR *et al.*, 2003), were implemented following discussion with government, farming and scientific representatives. This policy has been widely promoted to veterinarians and rehabilitators (Mullineaux, 2003b; Mullineaux, 2007a; Mullineaux, 2007b; Mullineaux, 2008), and regulates the treatment of adult badger casualties and orphans.

Several ecological features make badgers suitable maintenance hosts of *M. bovis*; badgers survive for many years after acquiring infection (Clifton-Hadley *et al.*, 1995b; Gallagher *et al.*, 1998), they continue to reproduce (Delahay *et al.*, 2000), they shed infection through several routes (Clifton-Hadley *et al.*, 1993; Clifton-Hadley *et al.*, 1995b), they have social behaviour that spreads infection through the sett (Clifton-Hadley *et al.*, 2001), they use communal latrines (Delahay *et al.*, 2007b) and they fight spreading disease through contaminated bite wounds (Gallagher *et al.*,

1976; Gallagher and Nelson, 1979; Clifton-Hadley *et al.* 1993; Delahay *et al.*, 2006b; Jenkins *et al.*, 2008).

Active tuberculosis has also been shown to be a major cause of morbidity and mortality in badgers (Muirhead *et al.*, 1974; Gallagher and Nelson, 1979; Cheeseman *et al.*, 1988) although it is considered to be only the second cause of death after RTAs (Cheeseman *et al.*, 1988). Although badgers may live for many years with bTB (Clifton-Hadley *et al.*, 1995b) active disease causes weight loss and emaciation prior to death (Clifton-Hadley *et al.*, 1993). Post-mortem lesions are found in the lungs, broncho-mediastinal lymph nodes, liver, spleen, and kidney (Muirhead *et al.*, 1974; Gallagher *et al.*, 1976; Gallagher and Nelson, 1979; Clifton-Hadley *et al.*, 1993; Gallagher *et al.*, 1998; Gavier-Widen, 2001; Jackson *et al.*, 2008). bTB may influence biochemical and haematological parameters in badgers (Mahmood *et al.*, 1988; Chambers *et al.*, 2000). These factors may all have a clinical impact upon animals presented for rehabilitation although these have not previously been discussed in the literature.

Testing regimes for *M. bovis* infection in badgers are limited by the low sensitivity of suitable tests. The gold standard for testing has long been recognised as post-mortem examination and culture of lesions (Pritchard *et al.*, 1986; Clifton-Hadley *et al.*, 1993). The most efficient methods of testing live badgers for *M. bovis* available to veterinary surgeons in practice have been serological tests, in particular the indirect 'Brock' ELISA test (Goodger *et al.*, 1994a). Because of the low sensitivity of this test (40.7%; Clifton-Hadley *et al.*, 1995a) adult badger casualties presented for rehabilitation are not routinely tested for *M. bovis* infection (SWWR *et al.*, 2003) and the disease risk is controlled by isolating badgers in captivity and release at the exact location where they were found (SWWR *et al.*, 2003). The incidence of *M. bovis* infections in adult badgers presented for rehabilitation has not been previously investigated.

The significance of *M. bovis* infections in badgers as a zoonotic risk to the general public, veterinary staff and staff and volunteers at wildlife facilities must not be underestimated (LoBue, 2006; Thoen *et al.*, 2006), especially when possible

occupational infections have recently been described (Shrikrishna, *et al.*, 2009, Twomey *et al.*, 2010). Suitable risk assessments and health and safety precautions must be undertaken for those dealing with wildlife casualties (Best and Mullineaux, 2003), and badgers in particular (Mullineaux, 2003a).

6.2 Materials and methods

All adult badger casualties presented to QVH and SWWR between November 2002 and July 2006 were recorded and clinically examined as has previously been described. Adult badgers were not routinely tested for *M. bovis* infection. Between February 2004 and April 2006 funding was available to carry out additional clinical testing on casualties (2.5), including testing for *M. bovis* infection.

Blood samples were collected using jugular venepuncture into lithium heparin (for biochemical tests), EDTA (for haematological tests) and plain tubes (for *M. bovis* serology). Samples for biochemistry and electrolyte measurements were analysed within 30 minutes using an in-house dry chemistry analyser as previously described (2.5.1). Haematology samples were sent to Idexx Laboratories for full differential blood counts. Two sets of ranges were considered for interpretation of biochemical and haematological tests (Appendix 2.6); the normal ranges for canine samples and values of common parameters from badgers at Woodchester Park (Mullineaux, 2003a).

The adopted protocol for testing adult badgers for tuberculosis prior to release (SWWR *et al.*, 2003) states that adult badgers should not be tested and disease transmission should instead be limited by isolating the animals in captivity with release at the exact location where they were found (SWWR *et al.*, 2003). Samples for *M. bovis* serology were tested retrospectively to prevent influencing the clinical decision and outcome for the cases. Blood samples were centrifuged and serum separated and stored at -20C (2.5.4). Samples were sent to the VLA, Langford for analysis using the badger bTB ELISA ('Brock test').

From May 2004 swabs from large bite wounds were taken into charcoal transport media and sent to FERA, York for selective culture for *M. bovis* and spoligotyping of positive cultures.

Dorso-ventral radiographs of the head, forelimbs and chest of each badger and ventro-dorsal views of the abdomen, pelvis and hindlimbs were taken routinely. Further radiographic views were taken as clinically required.

Following the clinical triage process (2.3) and dependent upon the findings of clinical examination and clinical tests, badgers either received appropriate medical treatment or were euthanased on welfare grounds. Those animals successfully treated were rehabilitated and eventually released back to the wild.

6.3 Results

6.3.1 *M. bovis* positive animals

Four of 41 badgers (10%) were positive for *M. bovis* infection. Clinical details of the positive animals have been summarised (Table 6.1). Three animals (7%) were serologically positive and two badgers had culture positive wound swabs (5%); one badgers was positive on both serology and wound swab culture.

6.3.2 Data analysis of animals testing positive and negative

The small number of badgers testing positive for *M. bovis* (4) prevented meaningful statistical analysis compared to the 37 seronegative badgers. Several demographic parameters were however considered for the two populations in an attempt to illustrate any trends in the positive animals. Two juvenile animals testing negative for *M. bovis* were excluded from body weight and tooth wear assessments.

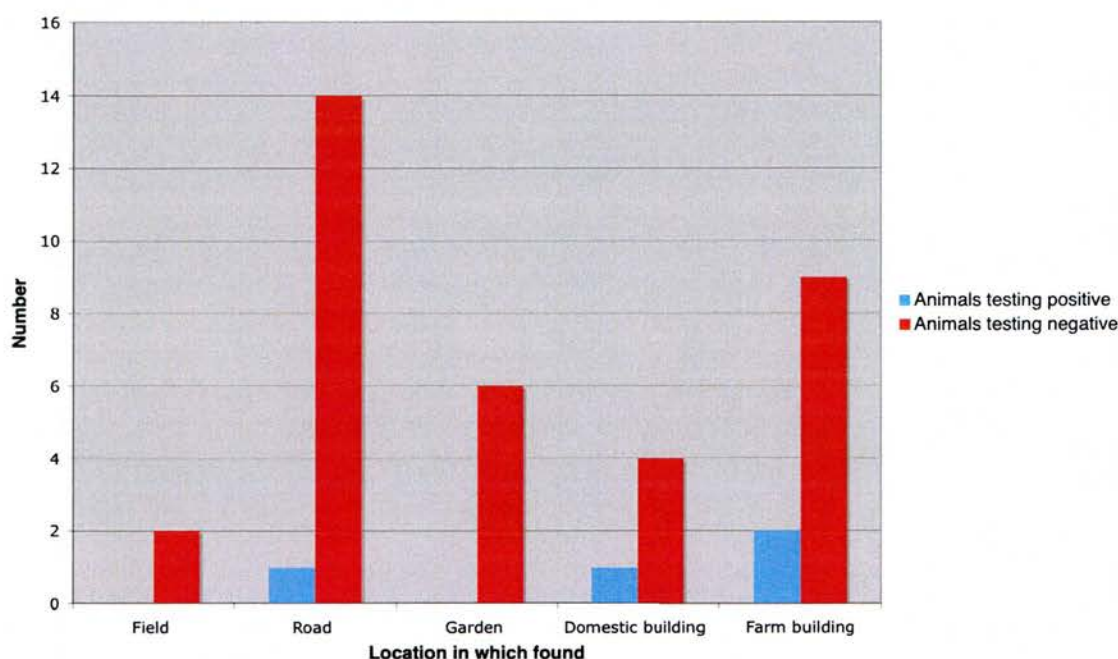
Table 6.1 Summary details of the four badgers testing positive for *M. bovis* infection

Parameter	Reference	Case number (Reference)			
		1 (EM60)	2 (EM61)	3 (EM65)	4 (EM82)
Location	6.3.3 Figure 6.1	Farm building (Calf housing)	Farm building (Hay barn)	Domestic building (‘Wendy House’)	At the roadside (Presumed RTA)
Sex	6.3.6	Male	Male	Male	Female
Condition	6.3.4 Figure 6.2	Poor	Poor	Poor	Poor
Weight (Kg)	6.3.7 Table 6.2	Not recorded	6.4	9.45	6.1
Age		Adult	Adult	Adult	Adult
Tooth wear score	6.3.5 Figure 6.3	0	0.5	0.5	0.25
Bite wounds	6.3.8 Table 6.3	No wounds	Wounds present	Wounds present	No wounds
Bite wound culture	6.3.8	No wounds	Positive spoligotype 11	Positive spoligotype 9	No wounds
Serology		Positive	Positive	Negative	Positive
Biochemistry and Haematology Summary	6.3.9 Table 6.4	Low ALB, high GLOB, elevated ALT and ALKP, high urea, PHOS and electrolytes, non- regenerative anaemia, leucopenia	High GLOB	High GLOB	High GLOB, elevated ALKP
Radiography Summary	6.3.10 Table 6.5 Figures 6.4, 6.5	Bone lesions associated with the distal femur and both ulnae	No significant findings	No significant findings	Bone lesions associated with the acetabulum, femur, distal humerus and a digit
Clinical summary	6.3.11 Figures 6.4, 6.5	Melena, dehydrated, moribund, disseminated osteomyelitis	Healing bite wounds, proliferative skin lesion	Significant wounds to Foot pads; abnormally worn	Chronic orthopaedic injury or infection
Outcome	6.3.12 Table 6.6	Euthanased	Died	Euthanased	Euthanased

6.3.3 Location in which badgers tested for *M. bovis* were found

The locations of badgers tested for *M. bovis* are shown in Figure 6.1, locations for the larger study population have been illustrated in Figure 3.2. Three of the *M. bovis* positive badgers were found in buildings; two in farm buildings and one in a domestic building. One of the positive animals was found at the roadside.

Figure 6.1 Location in which badgers were found in relation to *M. bovis* infection test results



6.3.4 Body condition of badgers tested for *M. bovis*

The body condition scores for the badgers tested for *M. bovis* are shown in Figure 6.2, those of the larger study population have been illustrated in Figure 4.1. All the badgers testing positive for *M. bovis* were found to be in poor condition.

6.3.5 Tooth wear grades of badgers tested for *M. bovis*

Tooth wear grades (0-1) were used as an estimation of age of badgers in the study population, the four animals testing positive had tooth wear grade of 0, 0.25, and 0.5 (two badgers) (Figure 6.3). Tooth wear grades for the whole study population have been shown in Figure 3.8.

Figure 6.2 Body condition scores of badgers in relation to *M. bovis* infection test results

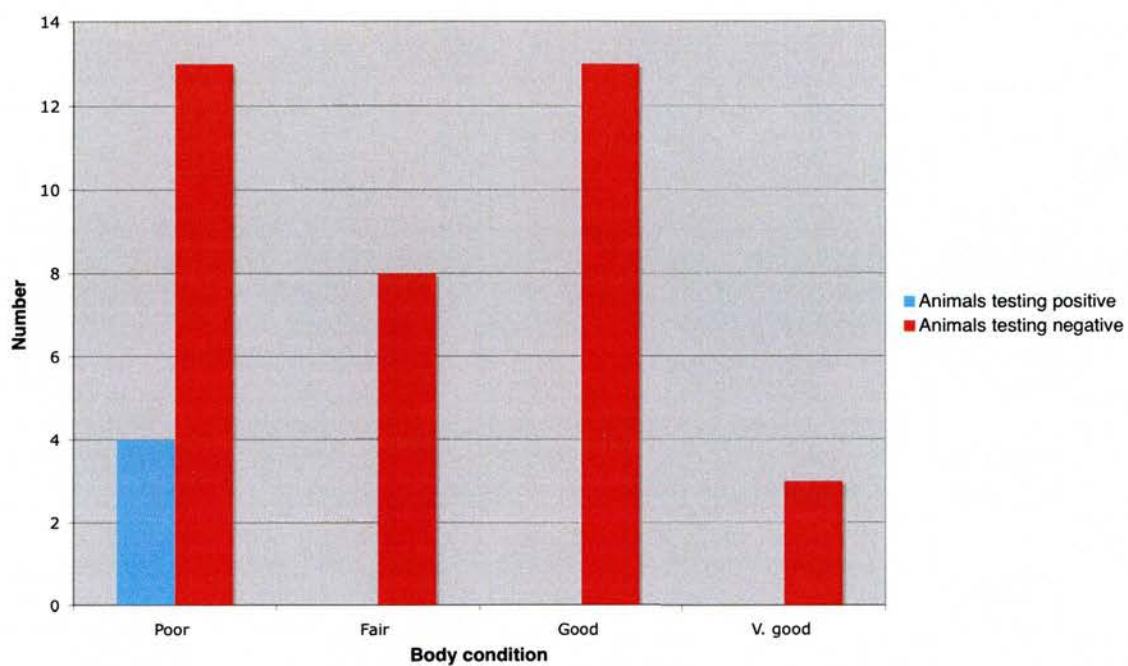
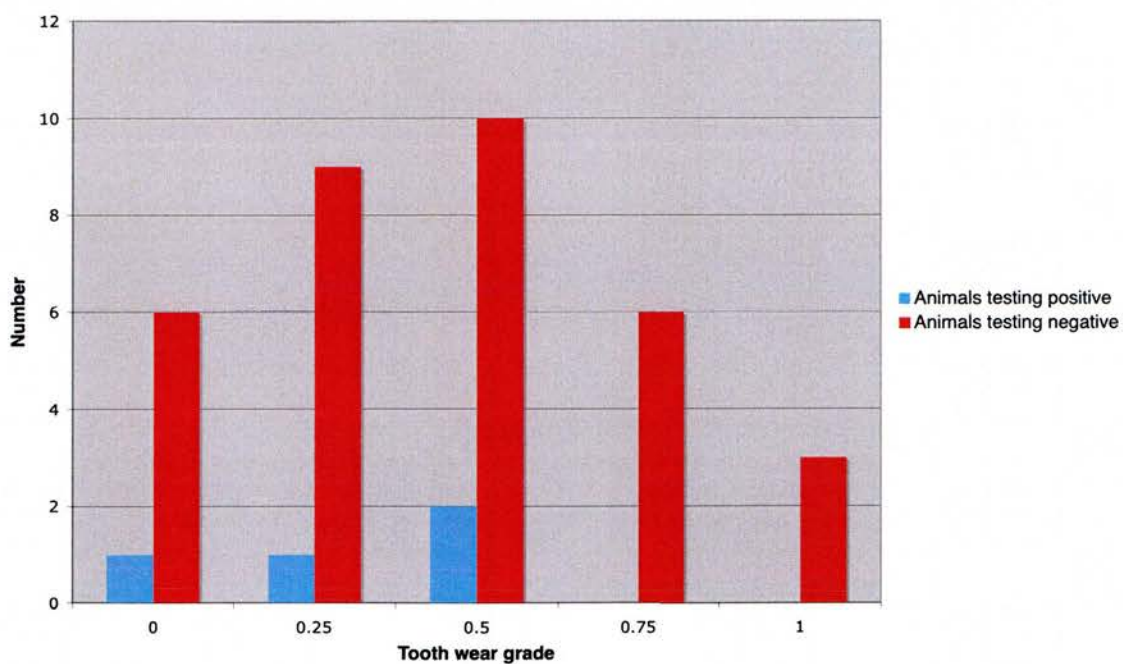


Figure 6.3 Tooth wear grades in badgers in relation to *M. bovis* infection test results



6.3.6 Sex of animals tested for *M. bovis*

24 of the badgers tested for *M. bovis* were male, of which three (3/24; 12.5%) were found to be positive, and 17 were female, of which one (1/17; 6%) tested positive.

6.3.7 Weight of animals tested for *M. bovis*

Badgers testing positive for *M. bovis* infection were on average 0.8 kg (10%) lighter than 29 badgers that were seronegative (Table 6.2) although this difference was not statistically significant.

Table 6.2 Weight of badgers tested for *M. bovis* infection

<i>M. bovis</i> test results	Weight (Kg)		
	Range	Mean	SD
Badgers test positive for <i>M. bovis</i> (n=3)	6.1-9.45	7.31	1.85
Badgers test negative for <i>M. bovis</i> (n=29)	5.27-14.0	8.13	2.41

6.3.8 Bite wounds in badgers tested for *M. bovis*

Bite wounds were present in 23/37 (62%) of *M. bovis*-negative badgers and 2 of 4 *M. bovis*-positive badgers (Table 6.3). The incidence of bite wounds in the larger study population is discussed in Chapter 5. Bite wound swabs were taken in 10 cases of animals with large wounds and two swabs (2/10; 20%) were found to be culture positive for *M. bovis*, spoligotypes 9 and 11.

Table 6.3 Bite wounds in badgers tested for *M. bovis* infection

<i>M. bovis</i> test results	Bite wounds present	Bite wounds absent
Badgers test positive for <i>M. bovis</i> (n=4)	2	2
Badgers test negative for <i>M. bovis</i> (n=37)	23(62%)	14 (38%)

6.3.9 Blood results for animals testing positive for *M. bovis*

Biochemical and haematological parameters for the individual animals testing positive for *M. bovis* are given in Table 6.4. Albumin/globulin and urea/creatinine ratios were calculated and plasma calcium adjusted for albumin concentration (Appendix 2.4). Values considered abnormal, based upon the reference ranges used (Appendix 2.6) and clinically significant are shaded. The low plasma glucose concentrations

Table 6.4 Biochemical and haematological parameters for badgers testing positive for *M. bovis* infection (clinically significant values are shaded)

Blood tests performed	Case No testing positive			
Biochemistry and electrolytes	1 (EM60)	2 (EM61)	3 (EM65)	4 (EM82)
Alkaline phosphatase (ALKP) IU/l	253	105	62	270
Alanine amino transferase (ALT) IU/l	112	54	60	108
Amylase (AMYL) IU/l	429	251	220	256
Urea (BUN) mmol/l	33.87	7.99	10.47	8.1
Urea:Creatinine ratio	1.12	0.24	0.19	0.19
Calcium (Ca) mmol/l	2.13	2.29	2.18	2.26
Calcium adjusted for Albumin mmol/l	2.66	2.54	2.46	2.41
Cholesterol (CHOL) mmol/l	1.83	2.97	4.00	7.21
Creatinine (CREAT) μ mol/l	29	33	56	43
Glucose (GLU) mmol/l	0.02	5.76	9.77	1.85
Phosphate (PHOS) mmol/l	3.91	1.70	1.97	2.77
Total bilirubin (TBIL) μ mol/l	2	8	8	16
Total protein (TP) g/l	60	93	74	88
Globulin (GLOB) g/l	46	68	50	59
Albumin (ALB) g/l	14	25	24	29
Albumin:Globulin ratio	0.3	0.36	0.48	0.49
Sodium (Na) mmol/l	167.3	152.1	154.1	157
Potassium (K) mmol/l	5.87	4.89	4.51	3.2
Chloride (Cl) mmol/l	129.2	114.0	116.0	111
Haematological parameters				
Red cells (RBC) $10^{12}/l$	5.00	8.18	7.85	7.84
Haemoglobin (Hb) g/dl	7.4	12.2	11.8	12.4
MCV fl	45.2	46.1	46.1	44.0
MCH pg	14.8	14.9	15.0	15.8
MCHC g/dl	32.7	32.4	32.6	35.9
WBC $10^9/l$	3.0	10.4	10.5	5.8
Neutrophils $10^9/l$	1.92	9.05	8.19	4.12
Lymphocytes $10^9/l$	0.84	0.94	1.37	1.33
Monocytes $10^9/l$	0.00	0.31	0.95	0.35
Eosinophils $10^9/l$	0.06	0.10	0.00	0.00

for EM60 and EM82 are considered to be a sampling error, most likely a delay in testing. Amylase concentrations were all low; this is not considered significant for the reasons discussed previously in Chapter 4. Blood results for the whole study group of 50 sampled badgers have been described (4.3.4) and discussed in Chapter 4.

6.3.10 Radiographs of badgers tested for *M. bovis*

Radiographs were taken in the four cases testing positive for *M. bovis* and in 30 of the cases testing negative. Radiographic abnormalities are summarised in Table 6.5. Two of the four *M. bovis* positive animals had bone lesions associated with lysis and proliferation at more than one site as described below (6.3.11.1 and 6.3.11.4) and illustrated in Figures 6.4 and 6.5. None of the *M. bovis* positive animals had visible lung lesions. Radiographic findings in the larger study population have been described (4.3.5) and discussed in Chapter 4.

Table 6.5 Radiographic findings in badgers tested for *M. bovis* infection

<i>M. bovis</i> test results	Abnormal radiographic findings		
	Thoracic	Abdominal	Skeletal
Badgers test positive for <i>M. bovis</i> (n=4)	0	0	2
Badgers test negative for <i>M. bovis</i> (n=30)	5 (16.7%)	0	14 (46.7%)

6.3.11 Clinical findings

The significant clinical findings of the four positive cases are illustrated in Table 6.1, additional detail is given below:

6.3.11.1 Case number EM60

This badger presented in a moribund state, it was hypothermic, dehydrated, bradycardic and bradypneic. There was faecal staining with melena around the perineal area. The right elbow had restricted movement on manipulation and the left stifle and right hock were palpably enlarged. Radiographs showed remodelling of both ulnae with widening of the right humeroulnar joint (Figure 6.4). The distal left femur was remodelled with gross distortion involving bone lysis and proliferation, this extended across the stifle joint to involve the proximal tibia (Figure 6.5). There was gross re-modelling of the right hock from the distal tibia to the proximal

metatarsus. The radiographic changes were consistent with chronic osteomyelitis with haematogenous spread from a primary site.



Left:

Figure 6.4 Dorsoventral radiograph of case EM60 illustrating bilateral changes to the ulnae and widening of the right humeroulnar joint



Right:

Figure 6.5 Ventrodorsal radiograph of the left stifle of case EM60 illustrating osteolysis and proliferation of the distal femur

6.3.11.2 Case number EM61

This badger was presented simply because it was felt to be in an inappropriate and inconvenient place. The badger had a large, healing rump bite wound and fractures of both lower canine teeth. On clinical examination there was a small hyperplastic lesion attached to the dermis of the right lateral elbow (suspected papilloma). Blood results showed hyperglobulinaemia but there were no other clinical or radiographic abnormalities.

6.2.11.3 Case number EM65

This badger had a missing upper canine tooth and missing and fractured incisors. There was a very large bite wound on the rump and additional wounds to the head, neck and body. The bite wounds on the neck and body had healed to scars whilst those to the rump and head were old but still open. The rump wound was inflamed and secondarily infected. The pads of the right forelimb were abnormally worn. Blood results showed hyperglobulinaemia with a low albumin/globulin ratio, and slight elevations in plasma glucose and plasma urea concentrations. Red cell parameters were below the canine range but within the badger ranges. Radiographic findings were normal.

6.2.11.4 Case number EM82

This badger was female and had previously lactated. The lower canine teeth were fractured or missing. There was muscle wastage over the right hind leg with reduced movement and crepitus of the right hip, and right elbow joints. Radiographic findings revealed new bone formation around the right acetabulum especially on the cranial aspect, the right femur had bone remodelling around the proximal third distal to the femoral head, the right distal humerus had new bone associated with the medial condyle and there was osteolysis and proliferation of the second metacarpal bone of the left foreleg. In the absence of histopathology, the radiographic findings of the hindlimb could have arisen either from trauma or bone proliferation (although no osteolysis was present) as a result of infection. Abnormalities in the right forelimb were considered to be consistent with chronic trauma (osteoarthritis), whilst the metacarpal lesion was thought to be a result of localised infection (osteomyelitis).

6.3.12 Outcomes for badgers tested for *M. bovis*

The possible outcomes for the animals brought into captivity were; release, euthanasia at some stage during the treatment process, unexpected death in captivity. The outcome for the 41 badgers tested for *M. bovis* infection (Table 6.6) revealed that the four badgers testing positive had not been released although some had spent time in captivity; cases EM60 and EM82 had been euthanased immediately following examination, case EM61 had died within 24hrs, EM65 was euthanased 3 days after examination because its condition deteriorated. Outcomes for badgers in the larger study population have been illustrated in Figure 4.13 and are discussed in Chapter 7.

Table 6.6 Outcomes for badgers tested for *M. bovis* infection

<i>M. bovis</i> test results	Overall outcome		
	Released	Euthanased	Died
Badgers test positive for <i>M. bovis</i> (n=4)	0	3 (75%)	1 (25%)
Badgers test negative for <i>M. bovis</i> (n=37)	13 (35.1%)	24 (64.9%)	0

6.4 Discussion

The politics of *M. bovis* infections in cattle and badgers greatly influence the way in which badgers are rehabilitated. As a result of farmers' concerns that released badgers might be responsible for spreading *M. bovis* infection to cattle the Ministry for Agriculture Fisheries and Foods (MAFF, now DEFRA) held a series of meetings in 2000 with interested parties to discuss badger rehabilitation. In 2003 the resultant 'Badger Rehabilitation Policy' was adopted by the major wildlife charities, SWWR, the Badger Trust (formerly the National Federation of Badger Groups, NFBG) and the RSPCA (SWWR *et al.*, 2003; Mullineaux, 2003b). The document addressed the control of *M. bovis* in rehabilitated badgers as part of a wider guide to the care and rehabilitation of badgers. The policy differentiates between how adult badger casualties and badger cubs are treated and rehabilitated with respect to *M. bovis* infection. Adult badger casualties are not tested for *M. bovis* infection for two reasons; firstly the risk of disease transmission is considered very low because adult badger casualties are strictly isolated and released where they were found because of their territorial nature, secondly there is no suitable live test for individual animals.

This thesis represents the first survey of *M. bovis* in badgers presented for treatment, rehabilitation and release, showing how such infection presents, the clinical decisions and eventual outcome, and the potential risk of infection to man and other animals in close contact.

Four of 41 badgers (10%) tested positive for *M. bovis*; three were identified using a single serological test. The most efficient commercial test available to veterinarians in clinical practice at the time of testing was the indirect 'Brock' ELISA (Goodger *et al.*, 1994a). Several authors have reported this test to have sensitivity between 37% and 53%, and specificity between 89% and 98% (Clifton-Hadley *et al.*, 1995a; Greenwald *et al.*, 2003, Sawyer *et al.*, 2007) making it useful for identifying infection in groups of animals, but of limited use in individual badgers. One badger in the study was negative on the serological test but positive on *M. bovis* culture of a wound swab. The number of badgers detected using a single Brock test (3/41; 7%) is likely to be lower than the true prevalence of *M. bovis* infection in the study population because of the low sensitivity. However, the sensitivity of the test has been shown to increase with more advanced disease (Clifton-Hadley *et al.*, 1995a; Chambers *et al.*, 2008) so clinical cases of tuberculosis are more readily detected than those badgers with recent infection or latent, non-clinical disease.

Most of the badgers in the present study originated from Somerset where there is a relatively low prevalence of bTB in cattle and most herds have routine TB testing every four years (DEFRA, 2010). The borders of the county have testing intervals associated with a higher prevalence of the disease in the neighbouring counties of Gloucestershire and Devon that contain some 'hot spot' areas (Bourne *et al.*, 2007a; DEFRA, 2010). During 2003-05 the surveys in Devon and Gloucester showed the prevalence of bTB in RTA badgers to be 5-11% and 19-25%, respectively (Bourne *et al.*, 2007a). Tuberculosis has been shown to be the main cause of death in several badger studies (Muirhead *et al.*, 1974; Gallagher and Nelson, 1979; Cheeseman *et al.*, 1988), and the second cause of all deaths in badgers after road traffic accidents (Cheeseman *et al.*, 1988). The identification of 10% of adult badgers in the present study in Somerset with *M. bovis* infection was therefore not surprising but highlights

the potential risks when sick and injured casualty badgers are presented to veterinarians and wildlife rescue centres.

The four badgers testing positive for *M. bovis* infection were found at the roadside (1) and in buildings (3); one badger in a domestic building and two in farm buildings. All three locations are common sites for casualty badgers in the present study (Figure 3.2). Ranging behaviour of badgers increases with tuberculosis due to an increase use of their own territory and by ranging further into other neighbouring territories (Cheeseman and Mallinson 1981; Garnett *et al.*, 2005). Increased ranging behaviour appears to increase with tuberculous disease progression but it is unclear whether this is due to the disease itself or a need for increased food resources. Conversely individual badgers with larger home ranges may have a greater risk of encountering infection (Garnett *et al.*, 2005). The increased ranging behaviour of tuberculous badgers might also increase their risk of RTA and need to seek sanctuary in buildings outside their usual territory.

The use of farm resources by badgers including the use of buildings, has been observed by many authors (Cheeseman and Mallinson, 1981; Sleeman and Mulcahy, 1993; Garnett *et al.*, 2002; Roper *et al.*, 2003; Pavlacík, *et al.*, 2004; Ward *et al.*, 2008; Sleeman *et al.*, 2008; Tolhurst *et al.*, 2009). The finding of *M. bovis* infection in badgers found in buildings is significant to rehabilitation since this type of interface with man was shown earlier (Chapter 3) to be the location of over half the casualties admitted for treatment in the present study. Many of these badgers were in good body condition and showed no evidence of injury or disease other than bite wounds (Chapters 4 and 5). Although healthy badgers are known to frequent buildings in search of food and shelter it has been suggested that diseased animals, especially those in extremis, might be more likely to seek refuge in farm buildings, and that badgers found in buildings may consequently be of increased risk in spreading *M. bovis* infection to cattle (Cheeseman and Mallinson, 1981). Infected badgers in farm buildings may also be a risk to man. Male badgers were more commonly found in buildings than females throughout the study (3.3.2), and all three male animals testing positive for *M. bovis* were found in buildings. Male badgers are suggested to have higher infection rates of *M. bovis* as described below. RTA was a

common presentation in female badgers (3.3.2), the female *M. bovis* positive badger came from the roadside.

Three male badgers and one female badger tested positive for *M. bovis*. Several authors have also found higher infection rates in male compared to female badgers (Gallagher *et al.*, 1976; Gallagher and Nelson, 1979; Cheeseman *et al.*, 1988). The sex bias results from both ecological factors and susceptibility factors in male animals and is seen in other wildlife diseases such as chronic wasting disease in deer (Cross *et al.*, 2009). In the present study male and female badgers were admitted in almost equal numbers (3.3.4) but there were too few *M. bovis* positive animals for meaningful statistical analysis. Male badgers in the study were more commonly found in farm buildings and this group may be a particular risk of *M. bovis* infection to cattle as described above.

All four badgers testing positive were in poor condition. Although many other badgers presented in the study were also in poor condition (Figure 4.1) it is likely, after considering the clinical signs and ancillary tests that the badgers testing positive were clinically affected by tuberculosis. The clinical signs of tuberculosis described in badgers are limited mostly to weight loss, causing emaciation (Clifton-Hadley *et al.*, 1993; de Lisle *et al.*, 2002). The weights of *M. bovis* positive badgers were lower than the 37 badgers that tested negative and lower than the mean for the whole study population (Table 3.3). Seasonal variation in weight is seen but three of four badgers that tested for positive *M. bovis* presented in the first quarter of the year when mean weight is highest (Clifton-Hadley *et al.*, 1993; Cresswell *et al.*, 1993). It is likely therefore that in the individual infected animals both their poor condition and low body weights were attributable to tuberculosis.

Tooth wear scores were used to age badgers but there are limitations to this method as discussed in Chapter 3, and any conclusions are further limited by the small sample size of only four *M. bovis* positive badgers. These badgers had tooth wear grades between 0 and 0.5 suggesting that *M. bovis* infection is found in animals below three years old. Tuberculosis is usually considered to be a chronic disease with many badgers breeding normally for many years (Clifton-Hadley *et al.*, 1995b) with

some developing early containment of disease or latent infections (Newell, *et al.*, 1997; Gallagher *et al.*, 1998). Badger cubs have been reported with *M. bovis* infection but disease prevalence is lower than in adults (Jenkins *et al.*, 2008). However, there are more visible lesions at necropsy (Jenkins *et al.*, 2008) suggesting that younger animals might also show more obvious clinical signs of disease.

In man the development of post-primary disease is lower in children than adults (Sutherland *et al.*, 1982; Dye, 2008), although other influences such as ethnicity and HIV infection are also influencing factors (Ormerod, 2008), whilst the development of extrapulmonary post-primary disease is more common in children (Shingadia, 2008). Human vertical transmission of mycobacteria may occur transplacentally via the umbilical vein to the foetal liver, through aspiration or ingestion of infected amniotic fluid or infected milk (Caserta, 2009), but most commonly occurs through airborne infection from close contacts (Shingadia, 2008). The route of vertical transmission of tuberculosis is dependent upon the stage of infection in the mother, as is also the case in the spread of *M. avium paratuberculosis* in cattle (Aly and Thurmond, 2005), sheep (Sharp, 2007) and non-domestic ruminants (Witte *et al.*, 2009). In badgers although vertical transmission of *M. bovis* is considered likely to occur and be important in maintaining infection within social groups (Cheeseman *et al.*, 1989; Delahay *et al.*, 2000), the mode of transmission is currently unknown (M. Chambers *pers. comm.*).

Bite wounds were found in two of the four animals testing positive for *M. bovis*. Bite wounds were a frequent finding in the larger study population of badgers occurring in 55% of all badgers (Chapter 5). Bite wounds are considered a route of spread of *M. bovis* infection between badgers (Gallagher *et al.*, 1976; Gallagher and Nelson, 1979; Clifton-Hadley *et al.* 1993; Delahay *et al.*, 2006b; Jenkins *et al.*, 2008). It has been suggested that tuberculosis arises from infected bite wounds in up to 14.1% of cases and is especially virulent (Gallagher and Nelson, 1979) with badgers infected in this way surviving one quarter of the time of those with the disease originating from other sites (Clifton-Hadley *et al.*, 1993). Bite wounding is considered a route for systemic infection to organs such as the liver, spleen and kidney through haematogenous spread from the site of infection (Gallagher *et al.*, 1976; Gallagher

and Nelson, 1979; Pritchard *et al.*, 1987; Clifton-Hadley *et al.*, 1993; Gallagher *et al.*, 1998; Jenkins *et al.*, 2008). The distribution of lesions at post-mortem examination differs from those infections via other routes (mostly respiratory) with a higher prevalence of visible lesions (Jenkins *et al.*, 2007). Only one of the two study badgers testing positive (EM65) had bite wounds that were considered a significant clinical feature but there was no evidence of secondary organ involvement detected by biochemical parameters or radiographs.

M. bovis was cultured from two of 11 large bite wounds. Sampling wound infections has very low sensitivity and in a study of 47 tuberculous badgers *M. bovis* was only isolated from wounds in three badgers (Clifton-Hadley *et al.*, 1993).

The interpretation of blood profiles in badgers presented as casualties can prove very difficult (Chapter 4) not least because of the wide range of injuries and diseases and the lack of an accurate history. Some workers have followed changes in biochemical and haematological parameters throughout the course of tuberculosis in both in badgers and man.

Renal lesions associated with tuberculosis found at post-mortem examination of badgers (Gallagher *et al.*, 1976; Gallagher *et al.*, 1998; Clifton-Hadley *et al.*, 1993; Gavier-Widen, 2001; Jenkins *et al.*, 2008) are thought to arise from haematogenous spread from the lungs or another primary focus such as a bite wound (Gallagher *et al.*, 1976; Gallagher and Nelson, 1979; Pritchard *et al.*, 1987; Clifton-Hadley *et al.*, 1993; Gallagher *et al.*, 1998; Jenkins *et al.*, 2008). Secondary renal lesions are also seen in humans with tuberculosis with a wide range of renal changes that may result in total destruction of the kidney (NHS, 2006; Kumar *et al.*, 2007; Ormerod, 2008). Hypercalcaemia and hypercalciuria may be part of this process with can cause nephrocalcinosis, renal stones, and calcification elsewhere in the urogenital tract (Sharma, 2000; Ormerod, 2008).

Significant renal pathology would result in elevations in blood urea and creatinine concentrations possibly accompanied by reductions in serum albumin concentrations and a non-regenerative anaemia (Heine and Lefebvre, 2007). However badgers may have elevated urea concentrations and urea/creatinine ratios as a result of dietary

factors (Chapter 4) as well as pre-renal influences such as dehydration. Elevations in creatinine concentrations are therefore more likely to illustrate true renal compromise in badgers. Significantly elevated blood creatinine concentrations have been found in other studies of tuberculosis in badgers (Chambers *et al.*, 2000). However, only one of the four *M. bovis* positive animals in the present study showed azotaemia, which clinical examination suggested had resulted from dehydration. In the present study population (4.3.4.3) those badgers with 'chronic disease' did not have elevated mean blood urea and creatinine concentrations, indeed the lowest mean creatinine was found in this group possibly as a result of chronic weight loss over weeks to months. The present study found no evidence to support the use of blood urea and creatinine concentrations as indicators of tuberculosis in badgers.

The liver (Gallagher *et al.*, 1976; Clifton-Hadley *et al.*, 1993; Gavier-Widen, 2001) and spleen (Clifton-Hadley *et al.*, 1993; Gavier-Widen, 2001) have also been found as sites for secondary tuberculous lesions in badgers at necropsy. Disseminated tuberculosis also causes hepatomegaly and splenomegaly in cats (Gunn-Moore and Shaw, 1997). Lesions occur in the liver and spleen in man where haematogenous spread results from a primary lung lesion via the pulmonary vein (Kumar *et al.*, 2007; Ormerod, 2008).

Liver insults typically result in elevations in liver enzymes such as alkaline phosphatase (ALKP), alanine aminotransferase (ALT) and gamma-glutamyl transferase (GGT) and functional liver changes may result in elevated bilirubin concentrations (Watson, 2005). However many of these changes are not specific for primary hepatic damage as enzymes may be released from other active tissues and/or the liver may reflect primary disease elsewhere in the body. Increased GGT concentrations were reported in one study in tuberculous badgers together with lowered bilirubin concentrations (Chambers *et al.*, 2000).

In the present study two of the four tuberculous badgers had elevated ALKP concentrations and one animal has an increased ALT concentration but these changes were not considered to be specific for *M. bovis* infection.

In man hypercalcaemia has been associated with tuberculosis and other granulomatous diseases caused by abnormal calcium metabolism arising from irregular production of 1,25-(OH)₂D₃ (calcitriol) by activated macrophages in pulmonary alveoli and granulomatous inflammation (Sharma, 2000). Hypercalcaemia may be seen in approximately 10% of human tuberculosis cases (Sharma, 2000) although there is some dispute as to its true clinical significance (Kelestimur *et al.*, 1996).

There are reports of hypocalcaemia in tuberculous badgers (Chambers *et al.*, 2000) but the validity of these low plasma calcium concentrations is compromised by low plasma albumin concentrations (Chapter 4). In the present study the four *M. bovis* positive badgers had adjusted calcium concentrations within reference ranges, as indeed did all animals in the wider study group (4.3.4.5) including those with evidence of chronic disease.

Plasma albumin concentrations fall and plasma globulin concentrations increase in most chronic disease processes in response to antigenic stimulation such as infection (Bush, 1991). Plasma protein concentrations would therefore be expected to vary according to the stage of infection and the location of associated bTB lesions; no such relationship has however been found in badgers (Chambers *et al.*, 2000). In tuberculous humans plasma protein concentrations vary throughout the course of the disease and are influenced by medication and nutrition (Dye, 2008; Peloquin, 2008). As significant effects on albumin/globulin ratios are associated with both time of year and body condition in badgers (Domingo-Roura *et al.*, 2001), the variation of plasma proteins during the course of tuberculosis would be expected to be pronounced. Three out of the four *M. bovis* positive badgers in the present study had elevated plasma globulin concentrations and one had a low plasma albumin concentration with a resultant low albumin/globulin ratio. Plasma protein values were however frequently abnormal in the whole badger study population (4.3.4.4) where 41% of badgers were hypoalbuminaemic and 51% were hyperglobulinaemic. The high prevalence of infected bite wounds in the present study badger population may explain the occurrence of so many abnormal plasma protein concentrations.

In human tuberculosis a normocytic anaemia and lymphopaenia are typically found although haematological parameters vary between individuals and throughout the disease course (Lombard *et al.*, 1993; Hussain *et al.*, 2004) and may be complicated by concurrent HIV (Harries and Zachariah, 2008; Pozniak, 2008). In badgers haematological parameters also vary with initial elevations in RBCs and WBCs followed by decreases as the disease progresses (Mahmood *et al.*, 1988). RBCs were found to be increased in infected compared to uninfected badgers in another study (Chambers *et al.*, 2000). The WBC type altered during the course of the disease with initial leucocytosis and monocytosis whilst a lymphopaenia developed later in the disease process (Mahmood *et al.*, 1988). In man, secondary TB resulting in Addison's disease (hypoadrenocorticism) may also influence haematological parameters (Ormerod, 2008).

Only one of the four *M. bovis* positive badgers in the present study case showed a neutropenia and nonregenerative anaemia associated with chronic disease. In the larger study population badgers with 'chronic disease' had the lowest group mean RBC and WBC counts (4.3.4.6 and 4.3.4.7) but were not significantly different from the other categories.

In man radiographic lung changes associated with TB include localised radio-dense parenchymal lesions, pleural effusion and miliary disease (Gordon and Mwandumba, 2008). Chest radiography remains the primary diagnostic test for TB in humans over 35 years old who have been vaccinated with BCG (NHS, 2006). Typically cases of primary human tuberculosis show hilar lymph node enlargement associated with calcification, and calcification of Ghon foci, but many show no radiographic findings (Gordon and Mwandumba, 2008). Post-primary cases have variable radiographic signs including lung infiltrates or consolidated areas, sometimes with cavitation in the cranial lung lobes, with or without mediastinal or hilar lymphadenopathy (Kumar *et al.*, 2007; Gordon and Mwandumba, 2008). Both miliary and diffuse lung densities have been associated with feline TB (Gunn-Moore *et al.*, 1996; Gunn-Moore and Shaw, 1997).

Caseation and calcification of tuberculous lesions in badgers has been described (Gallagher *et al.*, 1976; Clifton-Hadley *et al.*, 1993; Gavier-Widen *et al.*, 2001) and such calcification might result in tuberculous lesions being visible on radiographs as focal radiodensities within affected organs. Very small foci have been found in the lungs of badgers (Gallagher *et al.*, 1998), consistent with Gohn foci in man suggesting containment or resolution of the primary disease (Kumar *et al.*, 2007, Gordon and Mwandumba, 2008).

The classical description of miliary tuberculosis in man, arising from the haematogenous dissemination of infection from a primary lung lesion via the pulmonary vein back to other areas of the lungs, is actually uncommon (Kumar *et al.*, 2007; Gordon and Mwandumba, 2008). At necropsy of badgers such granulomatous lesions may be confused with lung adiaspiromycosis (*Emmonsia chrysosporium crescens*) or lungworm (*Aelurostrongylus falciformis*) (Gallagher *et al.*, 1998). Adiaspiromycosis is frequently found in the lung of badgers at post-mortem examination in common with other digging mammals (Gallagher and Nelson, 1979; Borman *et al.*, 2009) and may be more common in immunosuppressed badgers such as those with tuberculosis (Simpson and Gavier-Widen, 2000). Perhaps as a result of the multiple diseases that may result in a miliary lung pattern in badgers, some emphasis appears to have been put upon this distribution of tuberculosis (Gallagher *et al.*, 1998) rather than on other possible patterns of lung lesions.

Thoracic radiography of badgers has not been investigated as a method of diagnosis of tuberculosis probably for practical and financial reasons, although the technique has been discussed for research purpose (S. Lesellier *pers. comm.*). In man advanced imaging techniques such as CT and MRI and now preferred in many diagnostic situations, for example in miliary TB (Gordon and Mwandumba, 2008; Ormerod, 2008), and these also may be considered for badger research (M. Chambers *pers. comm.*).

None of the four badgers testing positive for *M. bovis* had radiographic lung lesions. Radio-dense lung lesions were identified in six of 55 badgers radiographed (4.3.5),

four badgers showed a diffuse alveolar pattern consistent with pulmonary haemorrhage following RTA, and two animals had widespread focal radio-densities consistent with calcified lesions of adiaspiromycosis (or other aetiology as described above). In small animal radiology it is customary to aerate the lungs at the time of exposure to increase contrast and allow for more reliable detection of lung pathology achieved by either taking the exposure at maximum inspiration in conscious animals or manual inflation in the anaesthetized patient (Dennis, 2003). If thoracic radiographs are to be used to aid diagnosis of bTB in badgers the animals should be anaesthetised to a depth that allows intubation and inflation of the chest. The depot intramuscular anaesthetic combinations usually used for research work and in clinical practice in badgers (1.5) do not always allow intubation and additional gaseous anaesthesia may be required. Risks arising from contamination of anaesthetic equipment, and in particular multi-use endotracheal tubes, would need to be addressed.

The radiographic bone lesions seen in two of the *M. bovis* positive badgers were of particular interest because radiographic osteoarticular lesions associated with TB are seen in man (Ormerod, 2008) but have not previously been demonstrated in badgers. Skeletal lesions in man are most commonly associated with the spine, followed by the hip, knee, ankle and wrist, but may occur at other bones sites. Lesions may be extremely debilitating; spinal lesions may result in eventual vertebral collapse ('Pott's disease'). Usually, but not exclusively, there is a single joint involved with associated muscle wastage and loss of function (Kumar *et al.*, 2007; Ormerod, 2008). The osteoporotic bone lesions may originate from granulomatous inflammation resulting in deregulation of calcitrol as described above (Sharma, 2000), although secondary renal hyperparathyroidism in chronic renal disease secondary to tuberculosis may be another pathogenesis for bone demineralisation. Peri-articular bone proliferation and destructive arthritis has also been described in feline tuberculosis, sometimes occurring at more than one site (Gunn-Moore *et al.*, 1996; Gunn-Moore and Shaw, 1997).

One of the *M. bovis* positive study badgers (EM60) had radiographic findings consistent with the bone lesions described in human TB (Kumar *et al.*, 2007;

Ormerod, 2008) and another badger (EM82) had some lesions consistent with infection rather than trauma. Two badgers that tested negative for *M. bovis* had proliferative and osteolytic bone lesions. Polyarthrititis has been described in badgers (Gallagher and Nelson, 1979; Lewis, 1997b) but the causes were not determined. Haematogenous spread of bacteria causing osteomyelitis is very uncommon in dogs and cats and usually involves the physes in neonatal animals and is accompanied by systemic signs of illness (Dunn *et al.*, 1992; May, 2002). Post-traumatic osteomyelitis; following surgery, bite wounds, RTA or gunshot injuries, is more common and usually localised to a single site (May, 2002; Langley-Hobbs, 2006). Dental wear indicated that all four badgers with osteomyelitis were 2-3 years old, suggesting that disease had originated before closure of the growth plates; tibial growth plates in badgers may not fully ossify until 18 months old (Page, 1973). Bite wounds in badgers as well as other trauma, such as RTA, may allow introduction of infection with haematogenous spread. In man bone haematogenous spread of TB from a primary infection may have a predilection for long bones resulting in lesions at such sites several years later (Ormerod, 2008). Further investigations of bone lesions in badgers in association with bTB are needed with additional histopathology and bacteriology to confirm the source of infection. From an animal welfare perspective, such lesions are very debilitating and cause chronic pain, with euthanasia the only ethical action.

While radiographic findings associated with calcification in feline tuberculosis have been reported in the abdominal viscera and mesenteric lymph nodes (Gunn-Moore and Shaw, 1997) no evidence of systemic calcification was noted in any of the badgers in the present study. In man, calcified lesions in organs associated with secondary tuberculosis including the gastrointestinal tract, kidneys, CNS and adrenals, are occasionally identified radiographically (Kumar *et al.*, 2007) although contrast studies are often required and CT or MRI preferred in many cases (Ormerod, 2008).

There are only brief clinical descriptions of tuberculosis in live badgers, which are limited to weight loss causing emaciation (Clifton-Hadley, 1993; de Lisle *et al.*, 2002), but these are not pathognomic for bTB. Behavioural changes, such as

increased ranging, have been suggested as a consequence of bTB infection (Garnett *et al.*, 2005) although these have not been attributed to specific CNS pathology and are more likely to result from either social or nutritional issues. Based upon post-mortem findings where the respiratory tract is the most common primary site of bTB infection in badgers (Gallagher *et al.*, 1976; Clifton Hadley *et al.* 1993; Nolan and Wilesmith, 1994; Gallagher *et al.* 1998; Delahay *et al.*, 2000; Jenkins *et al.*, 2008) respiratory signs would be expected but have not been reported. Radiographic findings in the lungs were reported in four badgers in the present study but were limited to discrete foci, which would not have caused respiratory compromise; significant pulmonary bTB lesions were not seen.

Clinical signs associated with damage to other major organs might be expected as lesions have been identified in the liver (Gallagher *et al.*, 1976; Clifton-Hadley *et al.*, 1993; Gavier-Widen, 2001), spleen (Clifton-Hadley *et al.*, 1993; Gavier-Widen, 2001) and kidney (Gallagher *et al.*, 1976; Clifton-Hadley *et al.*, 1993; Gallagher *et al.*, 1998; Gavier-Widen, 2001; Jenkins *et al.*, 2008). The extent to which such tuberculous lesions compromised hepatic, splenic and renal function was not determined in these reports. There are few reports of organ function tests using specific enzyme assays in the literature and such tests proved largely unremarkable in the present study.

In man the most common symptoms of tuberculosis are a cough, haemoptysis, weight loss, sweats, and general malaise (NHS, 2006; Gordon and Mwandumba, 2008; Schluger, 2008). Post-primary TB may involve dissemination of infection to major organs or joints as described above. Infection less commonly involves the meninges, pericardium, skin (Lupus vulgaris), lymph nodes, intestine, and urogenital organs (NHS, 2006; Kumar *et al.*, 2007; Ormerod, 2008). In the cat the clinical presentation of tuberculosis includes coughing, dyspnoea, lymphadenopathy (submandibular and mediastinal LNs), cutaneous lesions (masses and draining sinuses), lameness, joint swelling and arthritis, granulomatous uveitis and CNS signs (Gunn-Moore *et al.*, 1996; Gunn-Moore and Shaw, 1997).

The major clinical signs in *M. bovis*-positive badgers in the present study were general debilitation, bite wounds and skeletal lesions. Lymph node enlargement was not noted, although gross lymphadenopathy was described in two other study badgers; one *M. bovis*-negative and one untested for *M. bovis* infection. Ocular lesions were present in three study badgers, but were the result of trauma in two cases and a cataract in the third. The high prevalence of bite wounds in the present study meant that skin lesions and draining sinuses related to bTB may have been overlooked. The possibility of cutaneous tuberculous lesions should however be considered at all times when examining badgers.

Development and progress of clinical TB in man is greatly influenced by host immune responses. Immunosuppressive conditions especially HIV infection, immunosuppressive drugs such as TNF- α inhibitors and corticosteroids (Schwander and Ellner, 2008), together with genetic, nutritional, social and environmental factors (Gordon and Mwandumba, 2008) have an impact upon the disease. The effects of immunosuppressive conditions, unnecessary stress in captivity and use of immunosuppressive medications, in particular corticosteroids, must also be considered carefully in badgers and provide opportunity for future study.

Two of the four badgers that tested positive for *M. bovis* infection in the present study were euthanased following clinical triage, a third animal was euthanased subsequently as a result of clinical deterioration and the fourth badger died during its first night in captivity. Badgers with significant clinical disease, including tuberculosis, were identified during triage and were not considered suitable for release. Badgers without overt disease, especially those with latent infections, might however not be identified during triage and may test negative due to the low sensitivity of serological tests (Clifton-Hadley *et al.*, 1995a; Chambers *et al.*, 2008). The diagnosis of human tuberculosis is also difficult and relies upon clinical judgement in combination with sputum examination and culture, radiographic studies and immunodiagnostic tests (NHS, 2006; Schluger, 2008). Testing methods are discussed further below. It is unlikely that a definitive diagnosis of bTB in live adult badgers will ever be achieved in the rehabilitation situation and eventual release will depend upon the clinical judgement of the attending veterinarian.

The confirmation of *M. bovis* infection in four casualty badgers in the present study highlights a potential zoonotic risk to those people involved in their treatment and care. *M. bovis* is a recognised zoonosis and a possible cause of tuberculosis in man (Moda *et al.*, 1996; Johnston, 2006; LoBue, 2006) and is internationally classed as a Risk 3 pathogen for public health (Thoen *et al.*, 2006). Human infection with *M. bovis* in the UK is very uncommon and represents only 0.5-1.5% of confirmed human TB cases annually (de la Rua-Domenech, 2006), despite recent large increases in cattle herd bTB infections (Jalavak *et al.*, 2007). Occasionally, bTB cases arise from zoonotic infection including farm workers (Smith *et al.*, 2004) and veterinary staff (Shrikrishna, *et al.*, 2009; Twomey *et al.*, 2010), although occupational risk factors in these cases are often tenuous.

A wide range of wildlife species including badgers, present a bTB zoonotic risk to humans (Delahay *et al.*, 2001; Delahay *et al.*, 2007a). Other zoonotic infections may also be contracted from wildlife including badgers, although fortunately, the confirmed zoonotic infection rate in those vets treating wildlife species is low (Best and Mullineaux, 2003). It is a legal requirement (Health and Safety at Work Act, 1974) that employers have suitable risk assessments in place for all species their staff commonly handle (Best and Mullineaux, 2003; Cooper, 2003). Risks of infection from wildlife may arise from bites, scratches and contamination with saliva, urine, faeces, blood or pus (Best and Mullineaux, 2003). In the case of *M. bovis* in badgers, bacilli in saliva, urine, faeces and pus from wounds and lymph node abscesses (Clifton-Hadley *et al.*, 1993) pose potential sources of risk to handlers. The number of badgers testing positive in the present study was small and there were few clinical signs directly attributable to *M. bovis* infection. Whilst staff involved in the care of badgers must acknowledge the potential zoonotic risk of *M. bovis* infection, such risk must also be kept in proportion and contained by sensible precautions.

Precautions to avoid the risks involved in handling badgers, including the risk of *M. bovis* infection, in a veterinary practice situation have been detailed (Mullineaux, 2003a) and include suitable training in handling badgers, use of appropriate PPE, appropriate cleaning of surfaces and equipment, and the avoidance of procedures

with an increased risk of exposure such as post-mortem examination. Staff may also be vaccinated against TB using the BCG vaccine on the advice of their doctor. Risk assessments (Health and Safety at Work Act, 1974) must also consider those staff at particular risk of infection, including pregnant women and those with immunosuppressive conditions such as HIV (Ritacco *et al.*, 2006; Thoen *et al.*, 2006). Human tuberculosis is a notifiable disease under the Public Health (Control of Diseases) Act, 1984 and Public Health (Infectious Diseases) Act, 1988. Staff and volunteers at wildlife rescue centres, and members of the general public handling sick and injured badgers are also at potential risk from *M. bovis*. Road traffic accidents and badgers found in buildings were the most common reasons for presentation and badgers from these locations tested positive for *M. bovis* infection. In the present study all four *M. bovis*-positive badgers were found by members of the public and handled by wildlife rescue centre staff. It is a legal requirement that wildlife rescue centres implement health and safety policies to protect their staff and volunteers. Veterinary surgeons and rescue centre managers must also give appropriate advice to members of the public who find badger casualties to prevent potential injury and disease (Best and Mullineaux, 2003; Cooper, 2003), the current advice is to leave the handling of badgers to suitably trained and equipped personnel (Best and Mullineaux, 2003; Mullineaux, 2003a).

Badgers with *M. bovis* infection pose a risk to other badgers, other wildlife species and domestic animals, both whilst in captivity and following their return to the wild. However, such risks are largely eliminated following adoption of the 'Badger Rehabilitation Protocol' (SWWR *et al.*, 2003; Mullineaux, 2003b). Adult badger casualties are kept in strict isolation while in captivity, as much for social and territorial reasons as disease risk, thereby eliminating direct spread of infection. Direct transmission via aerosol or indirectly via drains and equipment is possible, and suitable environmental barriers and hygiene measures must operate in wildlife centres and veterinary premises. Transmission of infection between species during rehabilitation must also be avoided because many species are susceptible to infection (Delahay *et al.*, 2001; Delahay *et al.*, 2007a). In permanent wildlife collections, such as zoos and wildlife parks, bTB can be a significant problem despite strict biosecurity and quarantine procedures (West, 2006; Schmidbauer *et al.*, 2007). Care

must be exercised when hospitalising badgers in veterinary practices because bTB has been reported in cats (Wilesmith and Clifton-Hadley, 1994; Gunn-Moore *et al.*, 1996; Gunn-Moore and Shaw, 1997; Monies *et al.*, 2000; Monies *et al.*, 2006), and dogs (de Lisle, 1992; Pavlik *et al.*, 2002; Bauer *et al.*, 2004; Ellis *et al.*, 2006; Verma, 2006; Shrikrishna *et al.*, 2009; van de Burgt, 2009).

The Badger Rehabilitation Protocol states that all badgers are released where they were found (SWWR *et al.*, 2003; Mullineaux, 2003b) in acknowledgement of their territorial nature as well as disease prevention. The exact location is recorded using either GPS or geographical descriptions and OS map references. Adult badger casualties are not currently tested for *M. bovis* because the risk of disease transfer as a result of the rehabilitation process is considered to be very low, and the testing presents practical problems described below. Badger cubs that have been grouped during the rearing process, and translocated to release sites often remote from where they were found, are tested according to protocol (SWWR *et al.*, 2003; Mullineaux, 2003b; Mullineaux, 2007b; Mullineaux, 2008). Reassuringly, the present study found only four *M. bovis*-positive badgers and these badgers were identified with significant chronic illness during triage and were not released.

Ecological concerns following the release of rehabilitated individuals and groups of animals have been expressed (Robinson, 2002), especially when translocation of animals is involved (Griffith *et al.*, 1993; Wobeser, 2007). In the case of badgers, such concerns have increased following recent observations that disturbance of stable badger populations, through culling in an attempt to control bovine tuberculosis, may result in an increased risk of tuberculosis in cattle as a result of perturbation of the disease in badgers (Woodroffe *et al.*, 2006a, b; Jenkins *et al.*, 2007; McDonald *et al.*, 2008; Woodroffe *et al.*, 2008). There are no published studies of the social integration of rehabilitated adult badgers following release; anecdotal reports state that they are well accepted by their social group even after several months in captivity (P. Kidner, *pers. comm.*). The diagnosis of *M. bovis* infection in badgers in order to ensure that they are disease free upon release still remains problematic.

The diagnosis of *M. bovis* infection in live animals including man relies upon either the detection of primarily cell-mediated immune responses or the culture of the organism from body secretions (Cousins and Florisson, 2005). Current test methods in all species fail to reliably differentiate between recent exposure to mycobacteria, latent disease and active clinical disease (Cook *et al.*, 2008). Significant numbers of cattle are slaughtered in compulsory testing procedures as a result of a positive comparative skin test but have negative findings at gross post-mortem and laboratory examination since they have latent rather than active infections (Pollock and Neill, 2002). In man clinical signs, as described above, are used alongside diagnostic tests to establish those people at risk of clinical disease and potentially infectious to others (Schluger, 2008). Up to one third of the world's population may be infected with mycobacteria belonging to the *M. tuberculosis* complex (WHO, 2007) but only 5-10% are likely to become a disease risk (Sutherland, *et al.*, 1982; Dye, 2008), therefore the medical approach to diagnosis aims to identify clinically significant disease and avoid unnecessary treatment of cases with latent infections. In animals attempts to improve testing often assume a dichotomous approach ('infected' or 'not infected') (Drewe *et al.*, 2010) and do not differentiate between 'infected' and 'infectious' animals. As a consequence '*M. bovis* infection' and 'tuberculosis' are often used interchangeably in badger and cattle scientific papers, whilst in man 'tuberculosis' refers to 'a case of culture confirmed disease caused by the *M. tuberculosis* complex' (NCCCC, 2006).

Serological testing of captive badgers for *M. bovis* in the present study posed diagnostic, practical, logistic and financial problems. As in human medicine, an efficient diagnostic test that differentiated between infection ('infected') and active disease ('infectious') and could be performed in-house, alongside a clinical examination, would allow treatment decisions, including euthanasia in the case of badgers, to be focused upon clinical disease. Such testing would also help silence those critical of badger rehabilitation even if such opinion is sometimes poorly reasoned and politically motivated.

In cattle, and other species including man, TST using PPD to generate a delayed hypersensitivity (type IV) reaction is an important aspect of bTB diagnosis

(Monaghan *et al.*, 1994; NHS, 2006; Thoen and Ebel, 2006). TST is used at a herd level in cattle (Pfeiffer, 2008) and in man to diagnose latent TB and investigate disease at a population level often following localised outbreaks of disease (Cook *et al.*, 2008). Intradermal testing has however been shown to be ineffective in badgers for the diagnosis of *M. bovis* infection (Zuckerman, 1980; Little *et al.*, 1982; Mahmood, 1987a; Mahmood, 1987b) and is consequently not used at a group or individual animal level.

Culture and microscopy of sputum is very commonly used in man to detect mycobacteria in active clinical disease (NHS, 2006; Schluger, 2008). Various techniques have been described to enhance sample collection including sputum induction, gastric lavage, bronchoscopy and nucleic acid amplification assays (Schluger, 2008). Tracheal washes have been used for sample collection in animals such as meerkats where cultures of aspirates had high specificity but low sensitivity for diagnosis of *M. bovis*-infected individuals (Drewe *et al.*, 2009a). Culture of urine, faeces, sputum and wound swabs has been used as an adjunct to serological tests in badgers but detection is limited by the intermittent shedding of bacilli (Little *et al.*, 1982; Clifton-Hadley *et al.*, 1993; Gallagher and Clifton-Hadley, 2000; Chambers *et al.*, 2002), and such tests may be more appropriate during the latter stages of disease (Little *et al.*, 1982). The time taken for culture results (Little *et al.*, 1982; Crawshaw *et al.*, 2008) together with practical problems and potential health and safety risks associated with sample collection, have resulted in such techniques being dismissed as impractical in a rehabilitation situation. Unlike other test modalities culture techniques, alongside clinical findings as described above, identify badgers with active (infectious) TB rather than recent or latent disease (infected) and their use should not be dismissed.

The most efficient method of testing live badgers for *M. bovis* during the present study was the indirect 'Brock' ELISA test (Goodger *et al.*, 1994a) which measures specific antibody responses to *M. bovis*. This test has low sensitivity, between 37%-53%, but high specificity, 89%-98% (Clifton-Hadley *et al.*, 1995a; Greenwald *et al.*, 2003; Sawyer *et al.*, 2007), making it useful for testing groups but of limited use in individual badgers (Mullineaux, 2003b; SWWR, 2003). The sensitivity of the test

increases with more advanced disease (Clifton-Hadley *et al.*, 1995a; Chambers *et al.*, 2008) and in those badgers with a history of shedding *M. bovis* (Chambers *et al.*, 2002) so sensitivity may be of a lesser concern if the primary aim is simply to detect sick animals and those presenting particular zoonotic risk. Repeated ELISA tests increase the sensitivity of the test to 79.5%, but reduce its specificity (Forrester *et al.*, 2001). This method of ‘triple-testing’ has been employed by rehabilitators of badger cubs for several years in an attempt to ensure that they are free of *M. bovis* infection prior to release (Mullineaux, 2003b; SWWR *et al.*, 2003; Mullineaux, 2007b; Mullineaux, 2008). For badger adults however such testing would be problematic in terms of cost and unnecessary time spent in captivity.

The Brock ELISA test has not been commercially available since 1st April 2009 and has been replaced by a lateral-flow immunoassay for detection of *M. bovis* (Greenwald *et al.*, 2003; Lyashchenko *et al.*, 2003), which is commercially available as the BrockTB STAT-PAK® (Chembio Diagnostic Systems, Inc., Medford, NY). This test has been shown to be 49% sensitive and 93% specific for detecting tuberculosis in badgers (Chambers *et al.*, 2008) with a higher sensitivity (66-78%) in animals with more severe disease (Chambers *et al.*, 2008). For rehabilitation work the test has currently only been used in badger cubs. The preference is to send serum samples to an external laboratory (P. Kidner, *pers comm.*), but the test is quick and simple to use and could be applied ‘badger side’ in adult casualty animals. The availability of this test means that testing adult badger casualties for *M. bovis* should be reconsidered especially as *M. bovis* infection has been shown to occur in badgers in the present study. Although badgers with clinical bTB are unlikely to be released back into the wild, their rapid detection upon admission would limit infection risks and in this capacity the test would be a useful adjunct to other clinical findings. The use of a diagnostic test to indicate active infection, together with clinical signs of disease would aid the diagnostic process.

IFN- γ assays are used in man (NHS, 2006) and cattle (Gormley *et al.*, 2006) to detect cellular responses to *M. bovis* infection but they do not easily differentiate between recent, latent or active disease. A badger IFN- γ test has been developed (Dalley *et al.*, 1999; Dalley *et al.*, 2004; Sawyer *et al.*, 2007; Dalley *et al.*, 2008) and an ELISA

produced with sensitivity and specificity values of 81% and 94% respectively (Dalley *et al.*, 2008). This ELISA test is considered to be the most useful single tool for identifying *M. bovis*-free badgers for experimental work (Blancou *et al.*, 2009). The test has also been considered in combination with culture of clinical samples and the BrockTB STAT-PAK® to provide improved diagnosis of *M. bovis* infection in live wild badgers (Drewe *et al.*, 2010). No commercial IFN- γ assay is currently available and may be of limited use to rehabilitators because of concerns over the storage and transportation of samples (R. Delahay, *pers. comm.*). Overnight storage of samples from cattle showed that while interferon gamma production was reduced this did not significantly reduce the sensitivity of the test (Whelan *et al.*, 2004; Coad *et al.*, 2007) however, in man processing of samples is always completed within twelve hours (Nyendak *et al.*, 2008). The availability of such testing to rehabilitators would again provide an additional useful diagnostic aid either alone or in combination with other tests and clinical findings.

Whilst testing for *M. bovis* in live badgers continues to have limitations, post-mortem examination of badgers and bacterial culture from tissue samples using selective media (Gallagher and Horwill, 1977) remains the most sensitive method of detecting *M. bovis* infections in badgers (Pritchard *et al.*, 1986; Clifton-Hadley *et al.*, 1993). The sensitivity of this process has however been questioned recently because it may significantly underestimate *M. bovis* prevalence in badgers (Corner, 2006; Crawshaw *et al.*, 2008; Jenkins *et al.*, 2008; Murphy *et al.*, 2010). The present study concluded that post-mortem examination would be a useful tool not only for detecting clinical tuberculosis and latent *M. bovis* infection in badgers that died or were euthanased, but also adding to our knowledge of the clinical presentation of the disease; for example understanding the significance of bone lesions identified by radiography. For health and safety reasons post-mortem examinations where *M. bovis* is suspected are limited to approved laboratories. Post-mortem examination is carried out routinely in badger cubs testing positive to ELISA (now BrockTB STAT-PAK®) during the rehabilitation process (SWWR *et al.*, 2003). Improved post-mortem techniques (Murphy *et al.*, 2010) are being applied involving the culture of multiple tissue and lymph node samples to try and improve detection of infected badger cubs (L. Corner, *pers. comm.*). The emphasis on post-mortem studies in badgers is

however upon detection of *M. bovis* infection rather than identification of significant active infectious clinical disease. As discussed above the significance of such an approach to disease control is questionable in its role in the epidemiology of clinical disease in badgers and consequently transmission of infection to other badgers and cattle. Such an approach would not be considered useful for disease control in man where viable mycobacteria have been recovered from up to 50% of normal lung samples in endemic areas in patients dying from diseases other than tuberculosis (Hernandez-Pando *et al.*, 2000; Gordon and Mwandumba, 2008).

The final development that may have an impact upon badger rehabilitation is the potential availability of a bTB vaccine for badgers. A commercial BCG vaccine for badgers is being developed in Britain and Ireland and will be available for use in wild badgers later in 2010 (Lesellier *et al.*, 2006; Corner *et al.*, 2007; Corner *et al.*, 2008b; Lesellier *et al.*, 2008; Corner *et al.*, 2009; Lesellier *et al.*, 2009). It is possible that such a vaccine could be used in rehabilitated badgers following testing, to help further increase public confidence that released animals are disease free. Although some ecological concerns associated with vaccination of badgers against *M. bovis* have been expressed (Delahay *et al.*, 2003) a badger vaccine is viewed as the best way of controlling the disease in the wild population since other methods of disease control such as fertility control are not considered practical options (White *et al.*, 1997; Tuytens and Macdonald, 1998; Smith and Cheeseman, 2002).

6.5 Summary

The study showed that four badgers brought into captivity tested positive for *M. bovis* infection. The standard clinical triage protocol applied to these badgers resulted in three of them being euthanased rather than released, the remaining badger died unexpectedly. While the number of cases testing positive was small there is a zoonotic disease risk associated with *M. bovis* infections in badgers and suitable health and safety risk assessments must be in place in wildlife rescue centres and veterinary practices. The general public must be made aware of such zoonotic risks when handling debilitated badgers. Clinical examination accurately identified ill badgers though not those specifically infected with *M. bovis*. Clinical biochemistry and haematology analyses were of little additional benefit in defining TB. Radiography was a more useful technique for the detection of tuberculosis-related bone lesions, and inflated thoracic views would more readily detect early pulmonary lesions.

New and existing methods of testing adult badger casualties should be reviewed to help rapidly identify *M. bovis*-positive animals and incorporate this finding in clinical decision making in order to limit disease transmission. Any changes in testing regimens must however carefully consider the limits of the tests involved in detecting clinically affected potentially infectious badgers, the welfare of the badgers, and the financial and emotional issues that testing pose for rehabilitators.

Vaccination with BCG of badgers that test negative for *M. bovis* may be possible prior to release to further ensure their continued disease-free status. The social and ecological consequences of badger releases on existing badger populations and their effects on disease transmission require further investigation. Despite continued public enthusiasm for badger care, *M. bovis* infections in the species are likely to remain an emotive issue with entrenched views on both sides.

Chapter 7

Treatment, rehabilitation and release

7.1 Introduction

There are many reasons for veterinary involvement in the care of indigenous wildlife including the welfare of individual animals, conservation, disease monitoring, addressing the balance of mankind's actions, and professional satisfaction (Kirkwood, 2003; Cooper and Cooper, 2006; Wobeser, 2007; Vogelnest, 2008). In the UK there are few species endangered to the extent where conservation is a reason for the individual care of indigenous wildlife species and such treatment is consequently driven by animal welfare needs and demand from the general public. Veterinary associations in the UK broadly support the care of wildlife, indeed the RCVS 'Guide to Professional Conduct' charges the veterinary surgeon with a legal obligation to provide emergency care 'at least first aid and pain relief' to all animals including indigenous wildlife (RCVS, 2008). The BVA and RSPCA 'Memorandum of Agreement' further suggests that emergency care or euthanasia of small mammals and all wild birds brought to practices during normal surgery hours will be provided free of charge, although this agreement is not legally binding (BVA, 2008).

Most wild animals are presented to veterinary practices either by members of the general public or a wildlife rescue group. In order to maximise the likelihood of casualty animal release emphasis is placed upon the triage process when critical decisions are made regarding the likely survival of the animal after release; those considered unlikely to survive are euthanased for welfare reasons (Best and Mullineaux, 2003; Molony *et al.*, 2007; Vogelnest, 2008). Such clinical assessment is well within the skills of most veterinary practitioners and dealing with non-endangered species develops skills useful when presented with endangered species (Wobeser, 2007). Clinical assessment and initial treatment are followed by a period of rehabilitation usually at a specialist wildlife centre.

There are approximately 80 wildlife rescue centres in England treating British wildlife species with varying levels of charitable funding, and a wide range of facilities and standards of care. There is currently no statutory control of such facilities in Britain, while strict laws control similar facilities in other developed countries (Miller, 2000; Tribe and Brown, 2000; Hunt, 2003; Vogelnest, 2008). The success of treatment, rehabilitation and release of wildlife casualties depends upon

the facilities, suitably trained personnel, veterinary services, and adequate funding (Best and Mullineaux, 2003; Wobeser, 2007). A good working relationship between lay rehabilitators and their vets forms an essential part of the care and rehabilitation process (Miller, 2000). Rehabilitators face considerable emotional and philosophical issues as well as veterinary concerns (Sikarskie, 1992). On the positive side, as well as the personal satisfaction wildlife work may bring there is an additional educational benefit creating an environmental and conservation awareness which can educate others (Wobeser, 2007; Vogelnest, 2008).

Various bodies represent rehabilitators, either as single species groups (e.g. Badger Trust, Bat Conservation Trust, British Hedgehog Preservation Society), or as umbrella organisations (e.g. BWRC), and publish information on the care of British wildlife species in captivity.

Following rehabilitation, casualties are released back to the wild. Release is an underestimated risk of the rehabilitation process with the potential for high losses (Brown and Tribe, 2001; Vogelnest, 2008). Release also has potentially negative ecological, genetic and disease effects on existing populations (Cunningham, 1996; Brown and Tribe, 2001; Robinson, 2002), especially when animals are translocated before release (Griffith *et al.*, 1993; Wobeser, 2007). Despite such concerns there are limited studies into the success of the release process. Studies have tended to focus upon groups of casualty animals and birds such as populations affected by oil spills (e.g. Wernham *et al.*, 1997; Baker *et al.*, 1981; Mazet *et al.*, 2005) or the post-release monitoring of groups of juveniles including; birds (e.g. Sweeny *et al.*, 1997; Bennet and Routh, 2000; Fajardo *et al.*, 2000; Kelly and Bland, 2006; Drake and Fraser, 2008; Leighton *et al.*, 2008; Griffiths *et al.*, 2010), hedgehogs (Morris, 1993; Morris and Warwick, 1994; Sainsbury *et al.*, 1996; Morris, 1997; Morris, 1998; Bunnell, 2002), foxes (Robertson and Harris, 1995) and bats (Kelly *et al.*, 2008), and following the translocation of non-casualty healthy animals such as hedgehogs (Molony *et al.*, 2006).

There are currently few studies looking at the release rates of individual adult wildlife casualties following treatment and rehabilitation and no studies specifically

involving badgers. Information on the success of this process will help in the understanding of the effectiveness of clinical triage, veterinary treatment and care received during rehabilitation. Such information can be used to educate veterinarians and wildlife rehabilitators, and ultimately benefit the welfare of the badgers in their care.

7.2 Materials and Methods

Records were made of 123 badger casualties as previously described. Badger casualties were 'triaged' upon admission according to general principles applicable to wildlife casualties (Best and Mullineaux, 2003; Vogelnest, 2008) and those specific to badgers, as described in Figure 2.1. Details of clinical findings at triage and further diagnostic tests were recorded (Chapters 4-6). Based upon triage and clinical findings badgers were either euthanased for welfare reasons, treated for a period of time at QVH, moved to SWWR for further rehabilitation or immediately released back to the wild (Figure 2.2).

All medications were prescribed by the case veterinary surgeon. No prescription drugs are specifically licenced for use in badgers in the UK therefore choices were made with reference to current legislation, in particular the dispensing cascade (RCVS, 2008). The choice of treatments followed the principles used in small animal veterinary medicine (Ramsey, 2008), together with ease of administration; costs were not considered.

Badgers were hospitalised at QVH for the shortest possible period. The environment in a veterinary hospital was considered unsuitable for wildlife casualties due to noise, unsuitability of kennelling, and the risk of disease spread to and from other animals. SWWR have suitably qualified staff, including a RVN, and animals were moved as soon as they were medically stable. Badgers hospitalised at QVH were kept in stainless steel secure kennels away from other in-patients. Bedding was provided to allow the animal to bury itself and hide, and the kennel door covered to provide a dark environment. Observation, noise and handling were kept to a minimum and made as unobtrusive as possible. Food (usually tinned and dried dog food in the

short-term) and water were provided. Standard hospitalisation forms were used to record appropriate parameters and medical treatment (Appendix 1.2). A record was made if casualties were euthanased or died in veterinary care. Casualties considered suitable for rehabilitation were moved to SWWR or release sites.

Once at SWWR, badger casualties were kept in secure isolation pens with a variety of bedding materials; straw, blankets, shredded paper, together with an old car tyre to provide a latrine area. The badgers were provided with an omnivorous diet including dead chicks, chicken, dog food, cake and sandwiches. Daily records of food and water intake, medication, general demeanour and medical progress were kept (Appendix 1.3). Animals not progressing as expected were discussed with a veterinary surgeon and then re-examined either at SWWR or QVH (Figure 2.2); the standard triage criteria would then be re-applied. Prior to release, badgers were confirmed fit for release by a veterinary surgeon (Figure 2.1) as well as meeting all the criteria for release required by SWWR protocol (Figure 2.3).

Adult badger casualties were 'hard released' (Llewellyn, 2003) at night where they were found, without the provision of food, water or other support (SWWR *et al.*, 2003). Badger casualties were tattooed under licence prior to release in order to identify them if returned to captivity. Bilateral medial thigh tattoos using numerical codes provided by the Badger Trusts were used. Badgers were translocated to their release sites in cages covered with a blanket. Distances to release sites were usually under one hour as most adult casualties had been found within a 40 miles radius.

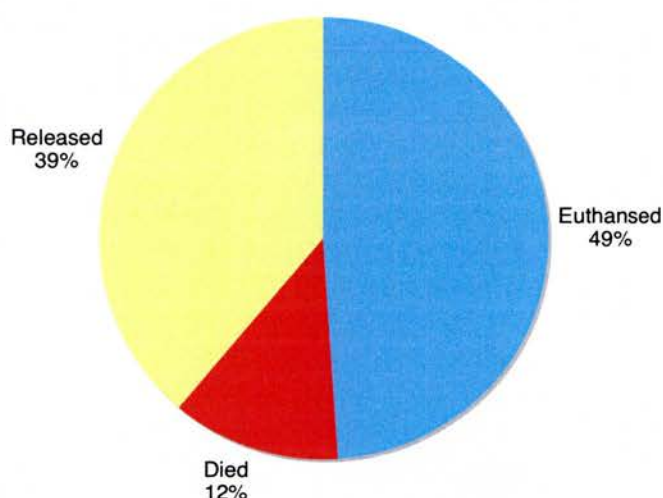
Outcomes for the badgers in the study could be determined from QVH and SWWR record sheets, together with duration spent in captivity and treatments received during that time. These parameters were then compared to other demographics allowing conclusions to be drawn regarding the types of casualties most likely to be successfully released and the quality of the triage process and care received.

7.3 Results

7.3.1 Overall outcome

The eventual outcomes for the 123 badgers in the study group were reported; 60 were euthanased, 15 died and 48 were released (Figure 7.1).

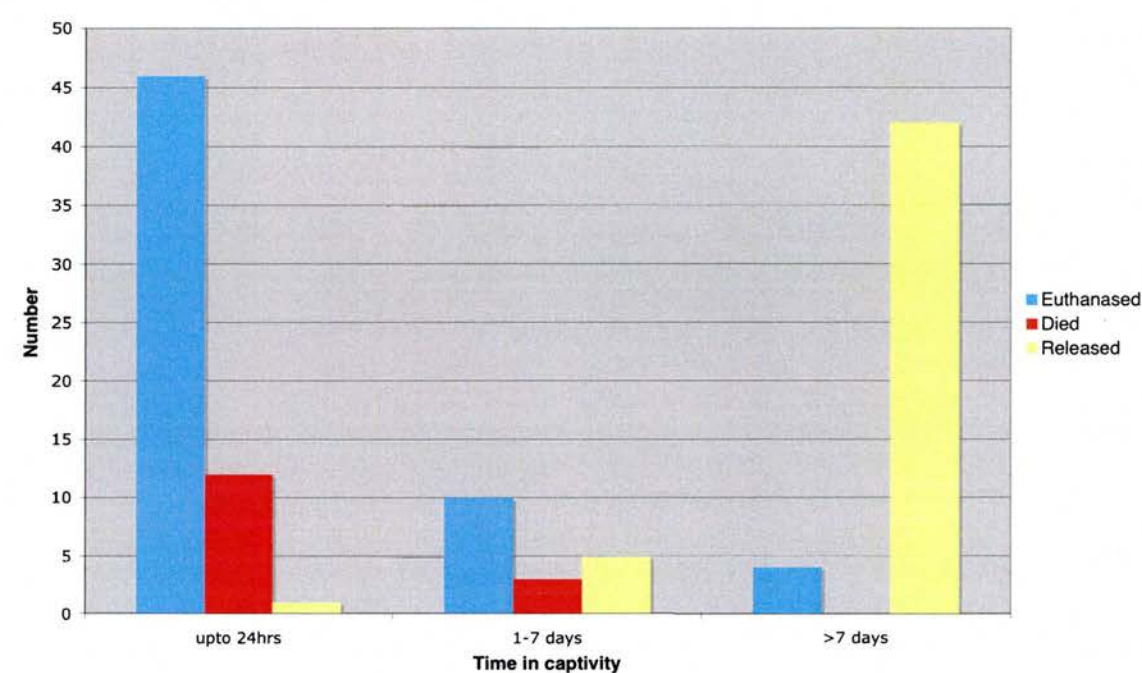
Figure 7.1 Summary of final outcome for 123 study badgers



7.3.2 Outcome at different intervals post admission

Outcome was considered at various intervals during the rehabilitation process; the first 24hrs in captivity, one to seven days post admission and after seven days (Figure 7.2). Where badgers were euthanased for welfare reasons mostly this occurred within the first 24 hours (46/60; 77%). 12 of the 15 badgers (80%) that died unexpectedly did so within the first 24 hours. 42 of the released 48 badgers (88%) were returned to the wild after seven days.

Figure 7.2 Outcomes for badger casualties during three time periods following admission



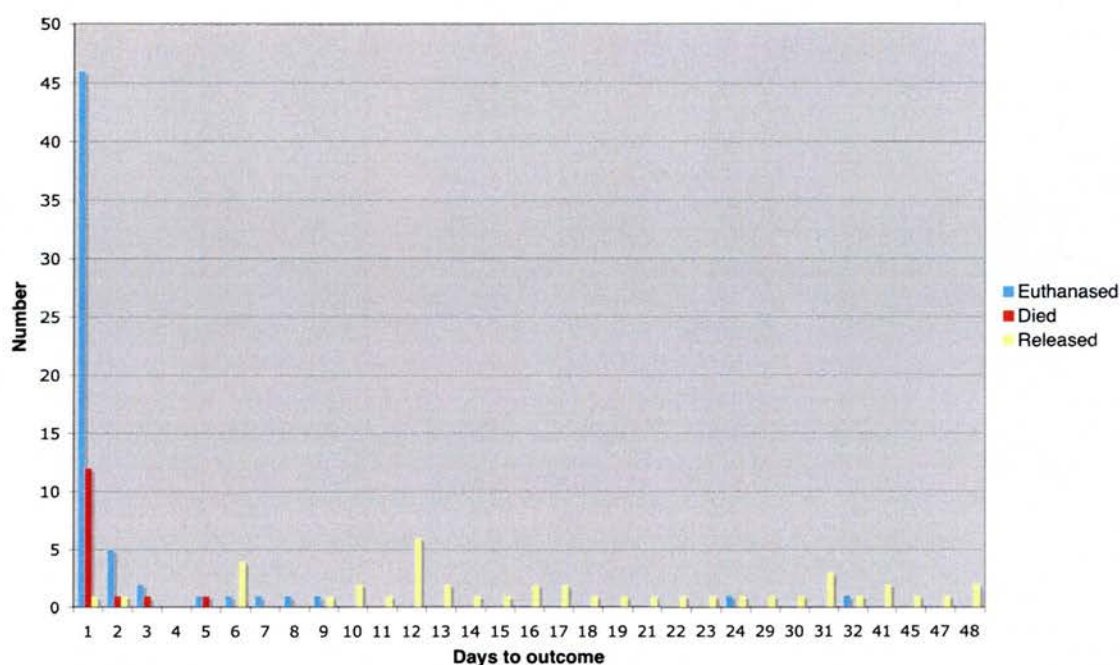
7.3.3 Time spent in captivity

Badgers spent on average 21 days in captivity before release (Table 7.1) however there was no peak release time (Figure 7.3). The mean interval to euthanasia was 2.3 days, but this value is greatly influenced by two badgers that were euthanased after especially protracted periods of time. One badger had poor response to treatment of osteomyelitis of a nail bed with accompanying radial nerve damage, and the other sudden deterioration as a result of renal failure; they were euthanased after 24 and 32 days respectively. The median interval to euthanasia was less than 24 hours; the skewed distribution of interval to humane destruction is clearly shown in Figure 7.3. Twelve badgers died unexpectedly within 24 hours of initial triage and treatment.

Table 7.1 Number of days spent by badgers in captivity before final outcome

Final outcome	Number of days to final outcome	
	Range	Mean (SD)
Euthanased	0-32	2.3 (5.2)
Died	0-5	1.5 (1.1)
Released	0-48	20.7 (13.6)

Figure 7.3 Time spent in captivity by individual casualties before final outcome



7.3.4 Time spent in captivity before eating

Appetite in captivity could be determined in 112 badgers (Table 7.2) and most animals that ate (38/47; 81%) did so within the first three days. The maximum intervals to eating were 10 days in a badger that was eventually released, and 12 days in a badger that was euthanased after 24 days.

Table 7.2 Time spent in captivity by adult badger casualties before eating

Number of days before eating	Eventual outcome for badger		
	Euthanased (n=59)	Died (n=15)	Released (n=38)
Ate within 24hrs	2	0	1
Ate day 1-2	2	2	19 (50%)
Ate day 2-3	2	0	10 (17%)
Ate day 3 or after	3	0	6
Total eating	9	2	36 (95%)
Did not eat before outcome	50 (85%)	13 (87%)	2 (5%)

7.3.5 Treatment received

Pentobarbital solution for euthanasia and drugs for sedation or anaesthesia were not considered to be medication in this context; 46 badgers were euthanased on admission. Twelve badgers received no medication; four animals died before medical treatment could be administered and eight were released without treatment. For the remaining 65 badgers the types of medication are illustrated in Table 7.3; 35 badgers (54%) received more than one type of medication.

7.3.6 Number of days of medication received

The number of days of systemic medication received was recorded in 74 cases as illustrated in Figure 7.4. The mean course of medication lasted 3.5 (SD 3.3) days.

Figure 7.4 Number of days 74 badgers received medication during captivity (excluding those euthanased on admission)

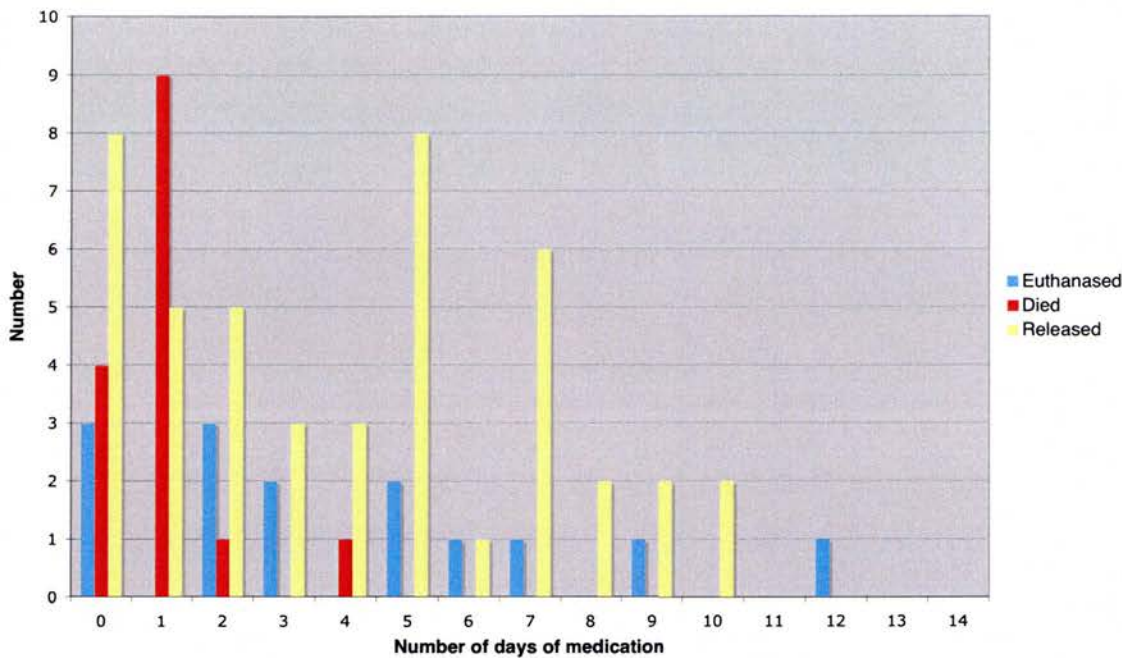


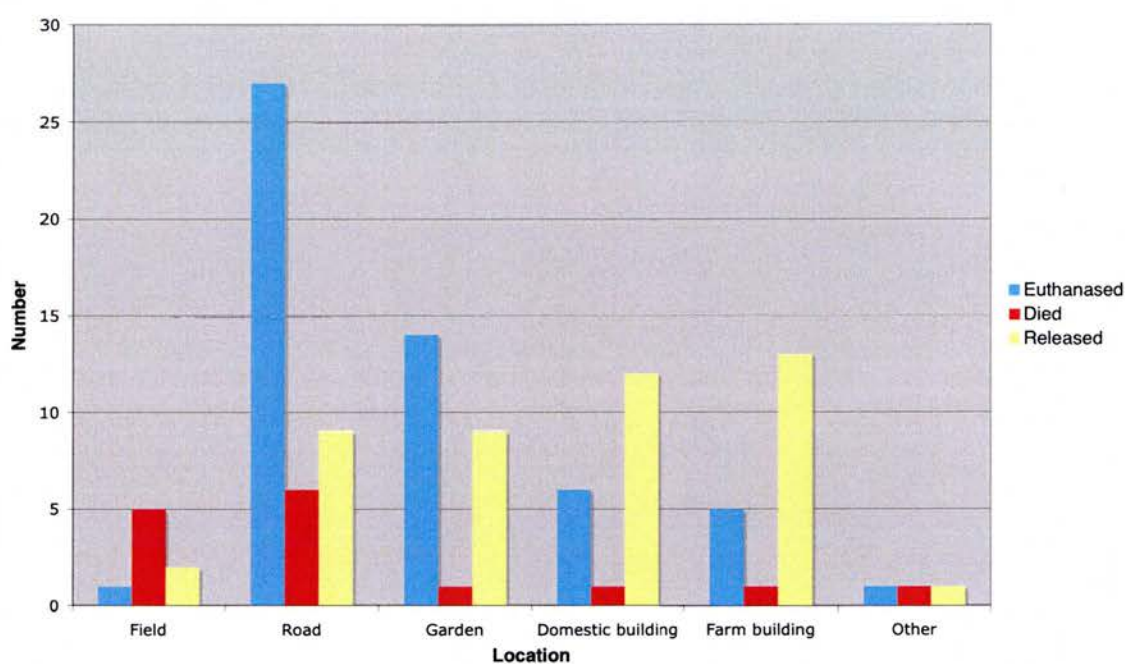
Table 7.3 Medication received by 65 adult badger casualties (excluding those euthanased on admission)

	Number receiving this treatment	Drugs used (number of cases)	
Antibacterial drugs	58 (89%)	Amoxicillin (<i>Amoxycare LA injection</i> [™] ; Animalcare Ltd., York) (22; 38%)	
		Amoxicillin and clavulanic acid (<i>Noroclav injection</i> [™] ; Norbrook Laboratories Ltd.) (32; 55%)	
		Clindamycin (<i>Antirobe capsules</i> [™] ; Pfizer Ltd., Sandwich) (4; 7%)	
Anti inflammatory drugs	33 (51%)	Dexamethasone (<i>Dexadreson</i> [™] ; Intervet UK Ltd., Milton Keynes) (7; 21%)	
		Meloxicam (<i>Metacam</i> [™] 5% solution for injection for dogs and cats; Boehringer Ingelheim Ltd., Bracknell) (25; 76%)	
		Carprophen (<i>Rimadyl injection</i> [™] ; Pfizer Ltd.) (1)	
Fluid therapy	14 (22%)	Crystalloid solutions (12; 86%)	Hartmann's solution (<i>Aquapharm No. 11 solution for infusion</i> ; Animalcare Ltd.) (8; 57%)
			Sodium chloride (<i>Aquapharm No. 1 solution for infusion</i> ; Animalcare Ltd.) (4; 29%)
		Colloid solutions (2; 14%)	Polygeline (<i>Haemacel</i> [™] ; Intervet UK Ltd.) (1)
			Succinylated gelatin (<i>Gelofusine</i> [™] ; B Braun Medical Ltd., Sheffield) (1)
Other medications	9 (14%)	Diazepam (Diazepam injection 10mg in 2ml, Hameln Pharmaceuticals Ltd., Gloucester) (2) Fusidic acid eye drops (<i>Fucithalmic Vet</i> [™] ; Dechra Veterinary Products, Harlescott) (1) Calcium gluconate (Calcium gluconate injection 10%, Hameln Pharmaceuticals Ltd.) (1) Glucose solution (<i>Glucose 40% solution</i> ; Dechra Veterinary Products) (1) Ivermectin (<i>Ivomec classic injection for cattle and sheep</i> [™] ; Merial Animal Health Ltd., Harlow) (2) Pethidine (<i>Pethidine solution for injection</i> ; Dechra Veterinary Products) (1) Buprenorphine (<i>Vetergesic</i> [™] ; Alstoe Ltd., York) (1)	

7.3.7 Location where found

The final outcome for 115 badger casualties was considered in relation to where they were found (Figure 7.5). The release rates for those badgers found at the roadside, in domestic buildings and in farm buildings were 21%, 63% and 68%, respectively. Badgers found in buildings had a significantly greater chance of release (combined buildings $P < 0.001$, farm $P < 0.01$, domestic $P < 0.05$) than those found in other locations such as by the roadside, gardens and fields. Badgers found by the roadside were significantly more likely to be euthanased than those in other locations ($P < 0.01$) and significantly less likely to be released ($P < 0.01$). Badgers found in gardens also had a low chance of release (37%) and were frequently euthanased (58%), however these outcomes were not significantly different from sub-populations of badgers found at the other sites.

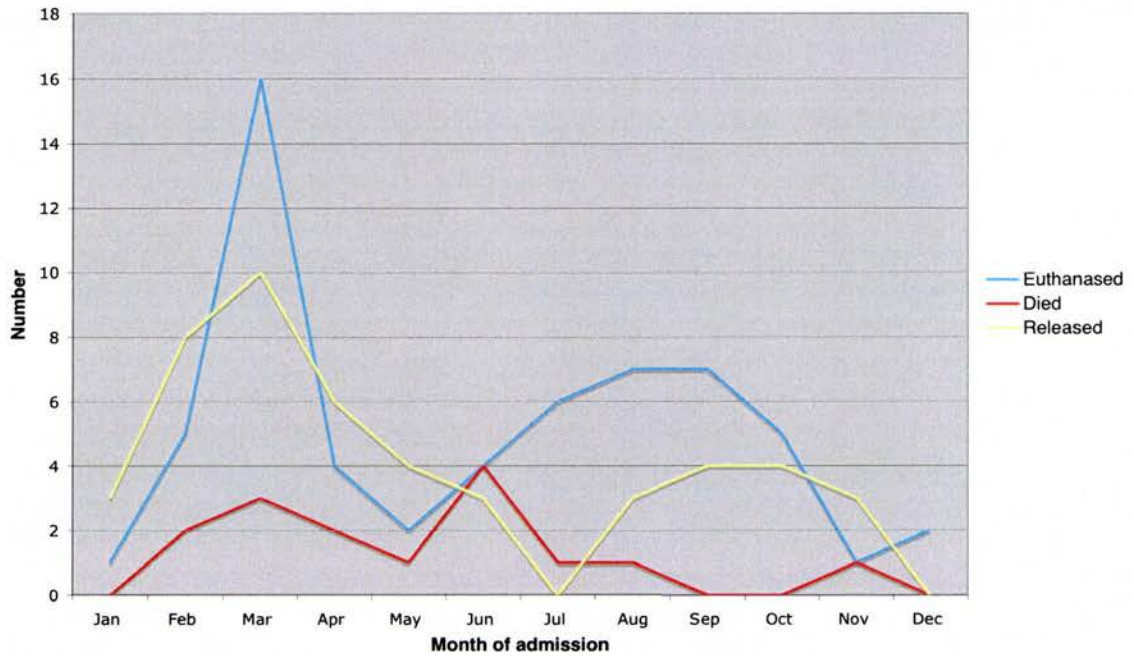
Figure 7.5 Outcomes for badgers according to where they were found



7.3.8 Month in which found

There was no significant effect of month in which animals were admitted and their eventual outcome (Figure 7.6). Trends in outcome largely followed those of admissions (Figure 3.1).

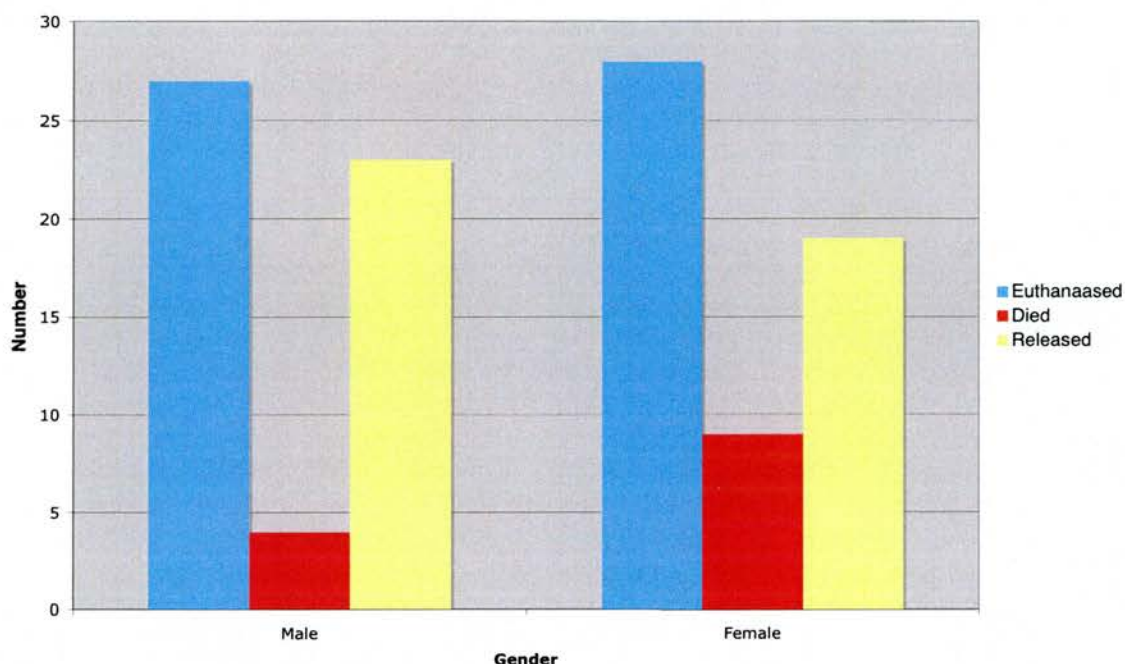
Figure 7.6 Outcomes for badgers according to the month in which they were found



7.3.9 Gender of badger

Equal proportions of male and female badgers were euthanased, slightly more male animals (43%) than females (34%) were released, however there was no statistical effect of gender upon outcome (Figure 7.7).

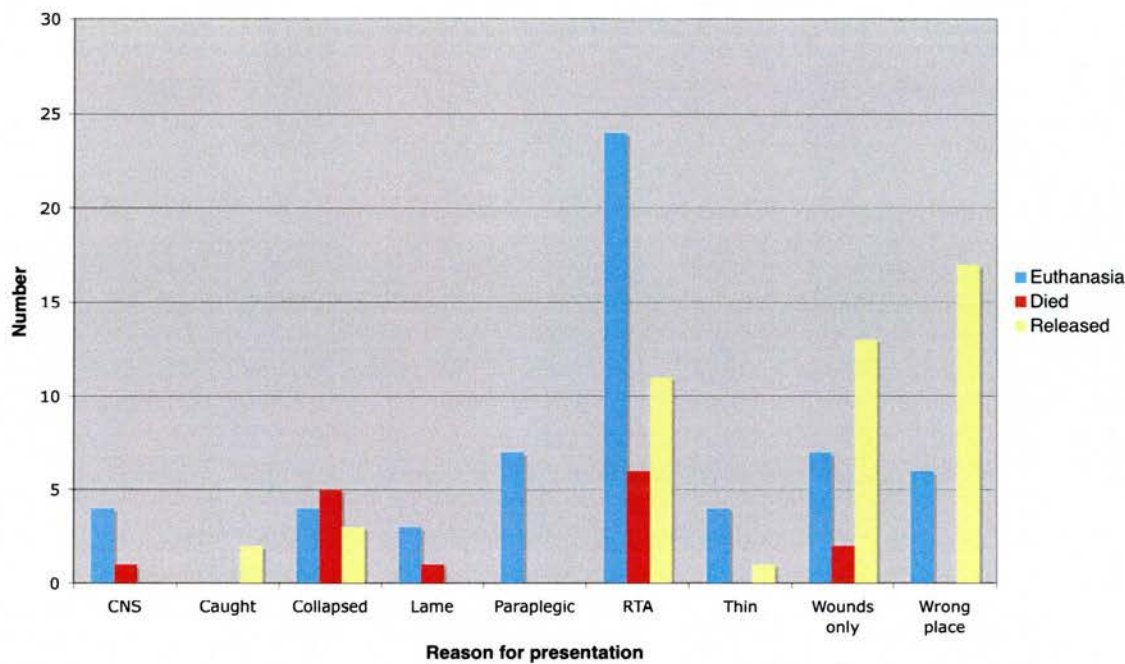
Figure 7.7 Outcomes for 110 badgers according to gender



7.3.10 Reason for presentation of badgers by members of the general public

The reasons for the initial presentations of the badger casualties was described by their finders in 121 cases (Figure 7.8). Significantly more badgers found ‘in the wrong place’ were released ($P < 0.001$), compared to those presented for other reasons. Badgers found at the roadside as suspected RTA by members of the general public had a poorer prognosis for release, and those thought to have only bite wounds a better prognosis, although these outcomes were not significantly different for the outcomes of other presentation categories. All paraplegic badgers and those with suspected CNS lesions were euthanased or died but there were too few badgers in the other groups for meaningful statistical analysis.

Figure 7.8 Outcome for badgers in relation to reason for presentation



7.3.11 Body condition

Body condition score in relation to outcome is illustrated in Figure 4.6. Badgers in poor condition were significantly less likely to be released than those in other body condition categories ($P < 0.001$), and those in good condition were significantly more likely to be released ($P < 0.001$).

7.3.12 Body weight

Badgers that were euthanased for welfare reasons, and those that died had lower mean body weight values than those badgers that were eventually released but this difference was not significantly different (Table 7.4).

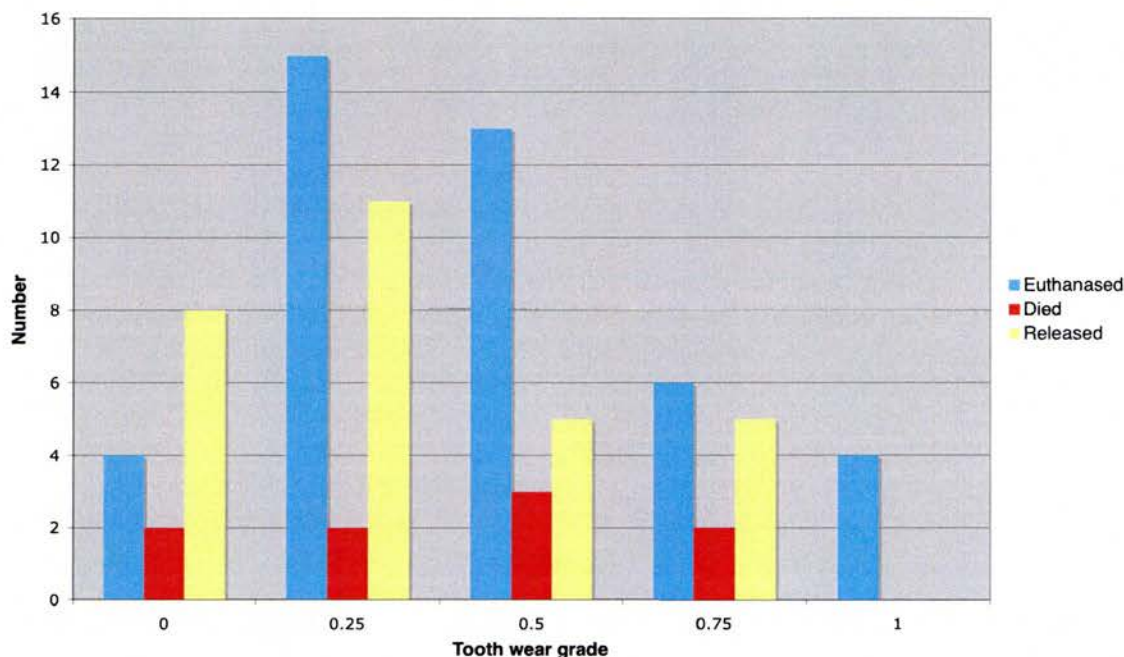
Table 7.4 Outcomes for badgers according to body weight (Kg)

Final outcome	Weight (Kg)	
	Range	Mean (SD)
Euthanased (n=44)	5.3-13.72	7.93 (2.37)
Died (n=11)	5.7-15.7	8.12 (3.26)
Released (n=28)	6.4-12.86	8.66 (1.91)

7.3.13 Tooth wear

Tooth wear was used as an indication of age in adult badgers in the present study. There was no significant relationship between estimated age and outcome (Figure 7.9).

Figure 7.9 Outcomes for 80 badgers according to tooth wear grade



7.3.14 Bite wounds

The significance of bite wounds in relation to outcome has been discussed in Chapter 5 and illustrated in Figure 5.21. Release rates were significantly higher for badgers with bite wounds only compared to those badgers with bite wounds and concurrent problems ($P < 0.001$).

7.3.15 Clinical findings

The outcomes for badgers with varying clinical findings has been discussed in Chapter 4 and illustrated in Figure 4.13. Badgers euthanased following acute trauma (30/60 cases; 50%) and those euthanased due to chronic disease (15/60; 25%) were significantly more likely to be euthanased for welfare reasons than badgers in the other categories ($P < 0.01$). Acute trauma accounted for most deaths (8/15; 53%) but too few badgers were included in the other categories for statistical analysis. Badgers

with bite wounds (29/48; 60%) had a significantly better prognosis for release ($P < 0.001$) than those with other clinical findings and badgers with evidence of acute trauma (11/48; 23%) a significantly worse prognosis for release ($P < 0.01$) than those in the other categories.

7.3.16 *M. bovis* infection

M. bovis infection was detected retrospectively in four badgers (Table 6.1); three cases were euthanased and one badger died in captivity (Table 6.6).

7.3.16 Release

All the badgers eventually deemed fit for release were successfully translocated to their release sites and returned to the wild. Tattoos allowed for identification of the casualties if they returned to captivity or were found dead under other circumstances. There were no known returns of the study badgers animals post release.

7.4 Discussion

Within the present study population 49% of adult badger casualties were euthanased, 12% of animals died unexpectedly and 39% of badgers were successfully treated, rehabilitated and released. These results are in general agreement with other rehabilitation centres' results, although those studies included all species and juvenile animals; BWRC records from several centres suggest an overall release rate of 42% for all species but 31% for mammals (Best, 1999; BWRC, 2000). Figures for all species and ages at the RSPCA wildlife hospitals in England are similar; 39% (+/- 8%) of animals released (Molony *et al.*, 2007), approximately 37% euthanased, and 13% dying (A. Grogan, *pers. comm.*). Analysis of badger records in RSPCA hospitals found release rates of 32% for 2002-04 (Molony *et al.*, 2007).

The majority of euthanased badgers (77%) were humanely destroyed within 24 hours in captivity, often within a few hours of presentation. 17% of badgers were in captivity for up to a week before euthanasia, and only 7% of animals received care and treatment for longer than one week. Of the badgers that died unexpectedly, 80% died within the first 24 hours, the remainder died before the end of their first week in care. Nearly half the badgers (47%) had their prognosis determined within the first

24 hours in care. This 24 hour period was important because the intention was that all animals were examined (triaged) as soon as possible following admission to prevent unnecessary time in captivity and unnecessary suffering. Other surveys (Best, 1999; BWRC, 2000; Molony *et al.*, 2007) have considered outcomes at 48 hours post admission. Five more badgers in the present study were euthanased on day two and there was one further death giving a survival rate after 48 hours of 48% of admissions. BWRC figures suggest around 58% of mammalian casualties (not just badgers) presented to rescue centres survive the first 48 hours (Best, 1999; BWRC, 2000). In their analysis of RSPCA data, Molony *et al.* (2007) found 55% (+/-8%) of admissions of all species survived for at least 48 hours.

Overall the figures for these studies are comparable, however the slightly lower survival of badger casualties in the present study at 48 hours could be explained in several ways. The figures in the other studies included all species, not just badgers, so species variation and the presence of juvenile animals in their study populations could influence the results. Although Molony *et al.* (2007) found no significant effects of age upon survival, other studies have found a better prognosis for juvenile animals, for example Drake and Fraser (2008) found juvenile mallard ducklings brought into captivity had a 65% survival rate. In badger cubs release rates of 58% were achieved (2001-2008) at SWWR despite euthanasia of 16% of cubs as a result of a stringent bTB testing policy (SWWR *et al.*, 2003) (E. Mullineaux, unpublished data). Another variable in the studies might be the availability and timing of veterinary intervention. In most instances veterinary care was not immediately available in the centres contributing to the BWRC data (R. Best, *pers. comm.*), whilst animals in the RSCPA centres were said to have been clinically assessed by a veterinary surgeon or veterinary nurse but no details of how or when this was completed are given (Molony *et al.*, 2007). The SWWR triage process, and the relationship the charity has with QVH, resulted in most (82%) of badger casualties being attended by a veterinary surgeon within 24 hours.

Where badgers survived the first 24 hours in captivity only those released remained in captivity for protracted amounts of time. Only 7% of those badgers euthanased for welfare reasons were kept more than seven days and only two of these for more than

nine days (24 and 32 days). One young RTA badger had osteomyelitis of a front nail bed and radial nerve damage that failed to resolve with treatment and a decision was made to euthanase after 24 days. Another badger with bite wounds was euthanased after 32 days as despite an initial good response to treatment it suddenly deteriorated and biochemical parameters indicated impaired renal function. Only 20% of the badgers that died survived more than 24 hours, the longest surviving individual, a RTA badger, died on day five. Overall these figures are considered acceptable and reflect the triage process applied to the casualties in the study where few badgers were euthanased or died after the first day.

Analysis of wildlife casualty admissions to RSPCA Hospitals across all species reveals that animals were kept for long periods of time with severe injuries. Under the five classifications of severity of illness or injury used in the study, those animals in category four (deep tissue wounds and/or emaciated and/or bone fractures) survived in captivity 18 (+/-33) days, and those in the category five (moribund and/or blind and/or fractured pelvis) 23 (+/- 48) days (Molony *et al.*, 2007). It was not reported whether these animals died or were euthanased.

The triage policy used in the current study of badger casualties was rigorous and based upon the requirements for survival of a wildlife casualty (Best and Mullineaux, 2003) and in particular the badger when returned to the wild (Mullineaux, 2003a). Experience in dealing with badger casualties over many years has also undoubtedly resulted in a more critical appraisal of prognosis and less doubt to euthanase casualties when the prognosis is poor. Badgers in the RSPCA data set categories four and five had been treated although it was concluded that those in category five should in the future be euthanased immediately because they had a less than 10% chance of survival (Molony *et al.*, 2007). These badgers would undoubtedly have been euthanased upon veterinary examination during the more rigorous triage protocol applied at QVH. Several authors who have considered the ethics and welfare of treatment of wildlife species concluded that there is a potential welfare risk associated with inappropriate treatment and that the welfare of the casualty animal should override all other considerations (Cooper, 1989; Kirkwood and Sainsbury, 1996; Kirkwood, 2003; Cooper and Cooper, 2006). An efficient triage

process for wildlife casualties is an essential practical part of treatment and rehabilitation (Vogelnest, 2008).

Badgers spent up to 48 days in captivity before release with a mean captive time of 21 (+/- 15) days. The time spent in captivity was determined by the staff at SWWR and badgers were kept until they were fully recovered and considered fit for release. Bite wounds in particular took a long time to heal as discussed in Chapter 5. Although concern is sometimes expressed from an ecological viewpoint regarding time spent in captivity by badgers (R. Delahay, *pers. comm.*), a study of translocated hedgehogs suggested that a period of time in captivity resulted in increased survival after release (Molony *et al.*, 2006). The time in captivity may allow for the deposition of fat reserves, with animals better prepared for release following translocation compared with those returned immediately to the wild (Molony *et al.*, 2006). Issues regarding the territorial nature and social group status of badgers might generate problems on their return to a social group, however anecdotal reports suggest animals are recognised and accepted positively by others in their social groups even after several weeks in captivity (P. Kidner, *pers. comm.*), but more detailed observations are needed.

Appetite was used as the major indicator of progress of badger casualties whilst in captivity. Most casualties that were euthanased (85%) or died (87%) did not eat in captivity because these events occurred within 24 hours; most (95%) casualties that were eventually released ate whilst in care. One animal that was eventually successfully released did not eat for ten days, suggesting that badgers are able to survive in captivity for protracted periods without food. In the wild badgers are able to reduce their activity and food intake significantly during the winter months (Delahay *et al.*, 2008) and this may explain their ability to cope with reduced food intake for several days in captivity.

Badgers are described as opportunist omnivores, eating a wide variety of plant and animal matter, fruit and insects (Roper, 1997). Although earthworms (*Lumbricus terrestris*) are considered to be the most important foodstuff (Kruuk and Parish, 1985; Neal, 1988), intake of these can be very variable (Roper, 1997; Muldowney *et*

al., 2003). Badgers are true opportunists and eat farm feeds from troughs (Garnett *et al.*, 2003; Roper *et al.*, 2003) and in open feed stores (Garnett *et al.*, 2003; Roper *et al.*, 2003; Ward *et al.*, 2008; Tolhurst *et al.*, 2009) with a preference for cattle 'cake' (Tolhurst *et al.*, 2009). The diet fed in captivity is through practical necessity somewhat different to the wild badger diet and includes foods with a high palatability to encourage appetite. In early experimental studies captive badgers were fed a mixture of meat and vegetables and dog food, warm beef stew, warmed honey soaked biscuit, with chicken carcasses once a week (Little *et al.*, 1982). The guidelines for the rehabilitation and release of badgers suggest not dissimilar foods; dog and cat food, peanuts, fruit and fresh carrion (SWWR *et al.*, 2003). Dog food is suggested for the short-term feeding of badger casualties in veterinary practices (Mullineaux, 2003a). As dental caries have been reported in the badger (Andrews and Murray, 1974), although not in the present study, some consideration should be given during longer-term captivity to foods that support natural dental care such as raw meat and bones.

The choice of medication prescribed for badgers was determined by the case veterinary surgeon following clinical assessment. No drugs are specifically licensed for badgers but doses were extrapolated from those used in domestic species (Mullineaux, 2003b; Bishop, 2005; Ramsey, 2008) and prescribed under the Veterinary Medicines Regulations (2009) and the dispensing cascade (RCVS, 2008). Although medication could be disguised in food (for example in the body cavity of dead day old chicks), oral dosing was considered an unreliable method of medicating most badgers since appetite varied. For similar reasons medication via water was considered unsuitable. Intramuscular or subcutaneous routes were most commonly used. Antibiotics were injected in the caudal lumbar or gluteal muscles, with minimal restraint such as a heavy blanket over the badger's head (SWWR *et al.*, 2003).

89% of those badgers treated received antibiotics, as most cases had open soft tissue injuries as a result of RTA or bite wounds. Broad-spectrum antibacterials were chosen following standard prescribing principles (Bishop, 2005) because it was not possible to determine bacterial sensitivity prior to treatment and many animals had multiple conditions. The common choice of antibiotic was amoxicillin as a long-

acting formulation or in combination with clavulanic acid. Long-acting drugs were considered appropriate as a single dose for most cases, although occasionally treatments were repeated after 48hrs. Amoxicillin plus clavulanic acid gives a broader spectrum of drug activity including beta-lactamase producing organisms such as *Staphylococcus* spp. that might contaminate wounds, however daily injections of this drug are required. Oral clindamycin was used in a small number of cases with osteomyelitis of digits or infection within the oral cavity, but its use was restricted to those cases that were eating well.

Analgesic drugs were used in over 50% of cases treated because many conditions were considered painful. Pain delays return to normal behaviour, function and appetite (Holton *et al.*, 2001) all of which were prerequisites for badger release. NSAIDS (meloxicam or carprofen) were the predominant analgesic drugs used in badgers in this study. NSAIDS have a sound evidence base from use in small animal practice (Capner *et al.*, 1999; Slingsby and Waterman-Pearson, 2001), and have long duration of effect, usually for 24hrs (Lascelles *et al.*, 1994; Laredo *et al.*, 2004). In most cases, NSAIDS were used for five consecutive days to allow a clinical response whilst avoiding possible side effects (Innes *et al.*, 2010a, b). Opioid drugs were used in two cases but this class of drugs is limited in its application to wildlife due to durations of efficacy (<8hrs), necessitating multiple repeat administration (Lascelles *et al.*, 1994; Laredo *et al.*, 2004), and legislative controls (Kerr, 2007). There are no medical reasons for avoiding opioid use in badgers and multimodal analgesia using NSAIDS plus opioid is recommended (Capner *et al.*, 1999; Slingsby and Waterman-Pearson, 2001) especially in RTA trauma cases.

Seven badgers with suspected head and/or spinal cord trauma received a corticosteroid preparation rather than a NSAID. Although the use of corticosteroids has been advocated in wildlife for trauma and 'shock' (Stocker, 2005), especially in the larger species such as deer where capture myopathies are common (Green, 2003), views on the use of these drugs in human and animal medicine have changed greatly over the last decade. There have been no human or animal studies to suggest corticosteroids are of general benefit in trauma patients and indeed they have been associated with increased morbidity (Dewey, 2000; Adamantos and Corr, 2007). In

the case of CNS trauma maintaining adequate perfusion to damaged tissue (Platt, 2005; Sande and West, 2010) or reducing oedema through the use of hypertonic saline or mannitol have been indicted as the methods of treatment choice in both man and animals (Dewey, 2000; Platt, 2005; Adamantos and Corr, 2007). However, in many wildlife species such as badgers, trauma poses a difficult choice between ideal treatment (intravenous fluids) and the medical disadvantages of sedation or anaesthesia to allow it's administration over several hours, when a less ideal drug (corticosteroids) can be easily given by intramuscular injection. In light of human and other animal studies the use of corticosteroids in wildlife should be reviewed upon sound evidence base. One additional reason for limiting corticosteroid usage in badgers is the potential reduction in cell-mediated immunity that has resulted in dramatic mycobacterial replication in previously latent human tuberculosis cases (Mok *et al.*, 2005).

Intravenous fluid therapy was administered in 22% of cases, mostly in unconscious or moribund animals following RTA or because they were dehydrated for other medical reasons. Twelve cases received crystalloids and two cases colloids. Dehydration was treated using crystalloids to replace assessed fluid losses. Treatment of circulatory shock in the case of RTA was with high dose crystalloids (20-30ml/kg over 15-30 minutes) or colloids as selected by the attending veterinarian. There is no clear evidence in human or animal medicine of the benefits of colloids over crystalloids for trauma cases (Adamantos and Corr, 2007).

The choice of drugs in the study badgers was similar to those used in a study of RTA cats where 68% received analgesics, 62% antibiotics and 25% fluid therapy (Rochlitz, 2004). Other drugs used in the badgers included; eye medication for conjunctivitis, diazepam, calcium gluconate and glucose for seizures, and ivermectin for myiasis associated with wounds. Although the mean duration of medication was 3.5 days, some badgers received treatment for five or seven days. Response to therapy was assessed using criteria for release previously described in Chapter 2. Surgical treatments for RTA related injuries are discussed below.

The outcomes for badger casualties were considered in relation to demographic factors that help determine outcome, contribute to recommendations for the general public and wildlife rehabilitators, and assist veterinary surgeons during the triage process.

The prognosis for roadside casualties was poor, with significantly more badgers euthanased and fewer released from this location compared to other categories. The findings of the present survey were consistent with other badger studies where RTA was the major cause of death even in those populations with endemic tuberculosis (Gallagher and Nelson, 1979; Cheeseman *et al.*, 1987; Cheeseman *et al.*, 1988; Clifton-Hadley *et al.*, 1993). Traumatic causes of death as a result of accidents involving humans are common in all wildlife species with 25% of all presentations for this reason (BWRC, 2000). 40% of the causes of hedgehog mortality at rescue centres in the UK and the Netherlands were associated with human activity including RTA, garden and pet injuries (Reeve and Huijser, 1999).

Badgers are large and robust animals compared with other British mammalian species and many appear to survive initial RTA impact resulting in them being brought into captivity as casualties. The range of injuries sustained, as described in Chapter 4, included a high percentage of skeletal injuries including fractures that would have necessitated complex orthopaedic surgery and protracted convalescence in captivity without the certainty of a good prognosis. As badgers rely upon their forelimbs for digging fracture healing is of particular concern. Techniques used for fracture fixation in small animal practice include plate fixation, external coaptation, external skeletal fixation, and intramedullary pinning (Brinker, 1978; Denney and Butterworth, 2000). External coaptation for major and displaced fractures in active animals, such as badgers, is not suitable as the sole method of fracture fixation in most cases (Denney and Butterworth, 2000). Plate fixation would in theory be suitable for many of the fractures encountered. Although plated fractures require some time to reach clinical union, typically 5-12 months in animals over 12 months old (Brinker, 1978), plates are generally left in situ indefinitely in adult domestic animals allowing return to normal function over 6-8 weeks. The possibilities of future sinus formation over the plate or soft tissue irritation however, mean that

plates should ideally be removed before releasing wildlife casualties, making them unsuitable implants. Techniques allowing for easy removal of implants, such as external skeletal fixation (Carmichael, 1991), require longer periods for recovery usually involving removal of components in stages over 4-14 weeks (Langley-Hobbs *et al.*, 1996). Protracted recovery periods and issues associated with implant removal therefore makes most orthopaedic surgery in badgers impractical. Potential problems associated with osteoarthritis or chronic pain post fracture repair would also impact upon a badger's ability to lead a normal life in the wild. Most fracture cases in the study were therefore euthanased for welfare reasons; only one simple undisplaced radial fracture with an undamaged ulna was treated with external coaptation (support dressings) alone.

The low release rate (25%) and high mortality (63%) of badgers found in open field areas is initially surprising but for a badger to be captured in the open during daylight hours is unusual and would suggest a serious problem, although the clinical findings in this group included some badgers with only bite wounds. Badgers found in gardens had a better prognosis for release than those found in other open areas such as fields or at the roadside, perhaps because they were able to escape an initial injury or impact but were too debilitated to return to the sett.

The outcome for badgers found in farm and domestic buildings was significantly better than for those in gardens and in open fields. Several authors have suggested badgers visit farms regularly (Cheeseman and Mallinson, 1981; Sleeman and Mulcahy, 1993; Garnett *et al.*, 2002; Roper *et al.*, 2003; Sleeman *et al.*, 2008; Ward *et al.*, 2008; Tolhurst *et al.*, 2009) although the use of domestic buildings has not previously been described outside mainland Europe (Pavlacik, *et al.*, 2004). As discussed in Chapter 5 more badgers in buildings had bite wounds, especially male badgers, than those found in other locations. Badgers found in buildings including those presented simply because they were 'in the wrong place' were significantly more likely to be released than those found in other places. It appears that many otherwise healthy badgers actively seek refuge in buildings following territorial disputes and bite wounds. Although bite wounds resolve well in captivity there is also evidence that healing occurs in the wild (Delahay *et al.*, 2006b). A general

recommendation to members of the public finding badgers in such situations should be that they should be that they should remain undisturbed. However, as discussed in Chapter 5 it is difficult to determine the scope of all injuries without a full clinical examination and therefore other problems and diseases in individual animals could be overlooked. Badgers that remain in buildings for several days or those failing to eat or appear ambulatory should be caught and investigated further by a veterinary surgeon. Once in captivity the release of badgers with wounds before they are fully healed may create ethical and legal issues.

Too few badger casualties were admitted during several calendar months for meaningful statistical analysis. Seasonal trends in badger releases followed overall admissions and were influenced by the location (Figure 3.3) and reason for admission (Figure 3.5). Fewer than 30% of badgers presented in June, July and August were released largely because of the seasonal occurrence of RTAs. A similar seasonal peak in badger RTAs has also been described (Davis *et al.*, 1987; Cheeseman and Neal, 1996). Other studies of wildlife casualties found no significant seasonal effects on release rate (Molony *et al.*, 2007).

The lower release rate for female badgers was related to the increased number presented from situations carrying a poor prognosis such as RTA. Conversely, male badgers were found more commonly in buildings with bite wounds, which afforded a better prognosis for release. A review of all wildlife species casualties showed no significant difference between the sex of casualties and likelihood of release (Molony *et al.*, 2007).

The prognosis was poor for those badgers where clinical signs were sufficiently severe to be easily recognised and described by the finder using general terms such as neurological disease, severe lameness, paraplegia, and emaciation. Badgers involved in RTA had a similar poor prognosis. Significantly more badgers presenting with only wounds and those animals found 'in the wrong place' were released than other categories. A survey of wildlife casualty admissions, including badgers, also concluded that the severity of illness or disease made the casualty much less likely to be released (Molony *et al.*, 2007).

As discussed in Chapter 4, badgers in good body condition were significantly more likely to be released than those in poor condition because chronic disease typically causes loss of body condition. These findings suggest that body condition can be used as a simple guide for prognosis for casualty badgers alongside the more detailed veterinary triage process.

Mean body weights showed a similar trend to body condition with released badgers heavier than those that either died unexpectedly or were euthanased. However, the size and weight of badgers in the present study was highly variable compared to body condition, which prevented meaningful statistical analysis. In studies of optimum release size for hedgehogs, authors have found weight alone to be a poor measure of prognosis preferring the relationship of weight to size using girth measurements (Bunnell, 2002). A study of wildlife casualties presented to RSPCA centres showed no significant difference between the weight of casualties and likelihood of release (Molony *et al.*, 2007). Body condition is a better parameter than body weight for determining fat and protein reserves in other domestic species such as sheep (Russel, 1984) and appears to be a more useful indicator of prognostic indicator in wildlife.

Higher release rates (57.1%) were achieved in badgers less than one year old (tooth wear grade 0), while no badgers were released at tooth wear grade 1 (more than three years old). Conversely, a study of wildlife casualties presented to RSPCA centres, including juveniles, showed no significant difference between the age of casualties and the likelihood of their release (Molony *et al.*, 2007). Although badger cubs were excluded from the present study the prognosis for this group is usually good as has briefly been discussed above.

The clinical categories with the worst prognosis were acute trauma cases usually RTAs, where significantly more (61%) badgers were euthanased and significantly less (22%) released. Badgers with chronic disease (83%) were significantly more likely to be euthanased than other categories. Badgers with bite wounds only had a significantly better prognosis for release (76%) than other categories. However, such group classification does not obviate the need for thorough clinical examination

because 22% of badgers in the acute trauma group were successfully released. Molony *et al.* (2007) suggested that injury or illness categories with less than 10% survival should not be treated. It is difficult to define all injuries and illnesses in this categorical manner and a full clinical examination at triage is strongly recommended. For many species, including badgers, such examination will need to be carried out under sedation or anaesthesia by a veterinary surgeon or suitably trained RVN.

As described in Chapter 4, blood parameters required careful interpretation alongside clinical signs and were too variable as prognostic indicators not least because there are no established reference ranges. Most abnormal radiographic findings were associated with injuries sustained in RTA and although these were an aid to diagnosis most injuries could be palpated during the triage process in the sedated patient.

In Chapter 5 it was shown that although 74% of badgers with bite wounds only were released this figure fell to 18% where there was concurrent disease or injury. Badgers with wounds spent the longest periods in captivity until wounds had fully healed even though bite wounds are reported to heal well in the wild (Delahay *et al.*, 2006b).

bTB is a major cause of morbidity and mortality in wild badgers (Muirhead *et al.*, 1974; Gallagher and Nelson, 1979; Cheeseman *et al.*, 1988) as well as a zoonotic infection (OIE, 2005; LoBue, 2006), and the subject of much political debate (Bourne *et al.*, 2007b; King, 2007; More *et al.*, 2007), as discussed in Chapter 6. The triage process applied in the present study meant that no tuberculous badgers were returned to the wild. *M. bovis* infection does however continue to exert huge political influence upon the rehabilitation of badgers and this will undoubtedly remain the case.

All badgers were tattooed to allow identification and 'return' of casualties but none has been identified to date. Individual tattooed animals have been returned to captivity following re-entry into buildings after obvious territorial disputes (P. Kidner, *pers. comm.*). In other species tagging or banding prior to release has been used as a way of measuring the success of the release process, although it has mostly

been used to assess the success of captive reared juveniles rather than rehabilitated adults. Leg band return data, sometimes in conjunction with radio-tracking, has been used by several authors to assess the success of hand rearing, rehabilitation and release of birds for example; in tawny owls (*Strix aluco*) (Bennet and Routh, 2000; Leighton *et al.*, 2008; Griffiths *et al.*, 2010), barn owls (*Tyto alba*) (Fajardo *et al.*, 2000), western screech owls (*Otus kennecotti*) (Allbritten *et al.*, 2002); peregrine falcons (*Falco peregrinus*) (Sweeny *et al.*, 1997) and mallard ducklings (*Anas platyrhynchos*) (Drake and Fraser, 2008). In these studies the success of the methods of marking and tracking was often a limiting factor in establishing the success of release.

No problems were encountered during translocation in the present study and all badgers left the release sites successfully. In other studies the stress of handling has been found to reduce the survival of translocated red squirrels (*Sciurus vulgaris*) (Letty *et al.*, 2000) and rabbits (*Oryctolagus cuniculus*) (Wauters *et al.*, 1997). Historically, incidents have occurred where badgers died during translocation immediately following sedation for tattooing (P. Kidners, *pers. comm.*).

Post release monitoring of rehabilitated mammals via radio or satellite tags has largely been restricted to groups of reared and released orphan animals including fox cubs (Robertson and Harris, 1995), pipistrelle bats (Kelly *et al.*, 2008) and hedgehogs (Morris and Warwick, 1994; Morris, 1998; Sainsbury *et al.*, 1996). Radio tags have also used to follow a group of adult hedgehogs translocated from the Uist Islands to the British mainland (Molony *et al.*, 2006). No published studies are available regarding the tracking of individual badgers following their release from rehabilitation centres, although attempts have been made to track badger cub release groups (A. Grogan, *pers. comm.*). Radio collars have been used extensively in published ecological badger studies (Garnett *et al.*, 2002). The two most practical methods of tracking badgers are very high frequency (VHF) radio-telemetry and GPS (Cross *et al.*, 2009). Such methods have considerable limitations for veterinary surgeons and rehabilitators in terms of cost, resources and time, but would undoubtedly provide invaluable information regarding the longer-term survival rate.

Until survival rates for rehabilitated animals can be determined it is difficult to critically assess the rehabilitation process beyond the number of casualties that are successfully taken from admission to release. Where large numbers of animals have been released, for example following oil spills, it has been possible to evaluate the success of treatment, rehabilitation and release policies, and strategically plan for future disasters (Wernham *et al.*, 1997; OWCN, 2002; Mazet *et al.*, 2005). In most mammalian rehabilitation events the numbers are small and meaningful conclusions prove difficult. In most studies of released juveniles losses of between one and two thirds are seen, mostly occurring in the first 4-6 weeks post release (Sainsbury *et al.*, 1996; Morris, 1998; Fajardo *et al.*, 2000; Leighton *et al.*, 2008; Griffiths *et al.*, 2010).

Most authors agree that the success rates gained, even though not high, make the rehabilitation process worthwhile. However, too little consideration is given to the welfare of those casualties that do not survive. Improved release protocols have been successfully developed from a small number of studies such as the development of accepted release weight ratios in hedgehogs (Morris, 1998; Bunnell, 2002) and use of pre release fitness (flight conditioning) prior to release in pipistrelle bats (Kelly *et al.*, 2008).

As well as considering the success of release in terms of the survival of the casualty returned to the wild, the genetic and disease risks of released animals to other wildlife and livestock should also be considered, especially if casualties are translocated (Griffith *et al.*, 1993; Cunningham, 1996; Tribe and Brown, 2000; Brown and Tribe, 2001; Wobeser, 2007; Vogelnest, 2008; Hartley and Gill, 2010). In adult badgers in the present study such risks were minimised by releasing badgers where they were found (SWWR *et al.*, 2003). Although this policy is aimed at preventing the potential spread of *M. bovis* infection to livestock as well as catering for the social and territorial nature of the species, it has the additional benefit of limiting any negative genetic impact and disease risks upon badger populations. Significant local changes in badger numbers that might negatively impact upon other species such as hedgehogs (Young *et al.*, 2006) are also avoided.

The success of adult badger release in the present study depended upon the work of a dedicated wildlife rescue centre which works to a high standard of care adopting national and international policies for wildlife hospitals (Miller, 2000; BWRC, 2007a; BWRC, 2007b), and policies relating specifically to badgers (SWWR *et al.*, 2003). The financial costs of maintaining such centres and providing the veterinary care that wildlife casualties demand are considerable. The lack of licensing of rescue facilities in the UK means that a minimum standard of care cannot always be ensured and despite the high standards of many centres, improvements can always be made. Potential problems, such as disease transmission within centres, were recently highlighted by the case of Tyzzer's disease in an otter in a rehabilitation centre in Scotland (Simpson *et al.*, 2008).

A close working relationship with a veterinary practice is an essential part of wildlife rehabilitation and must be based upon skills sharing and discussion rather than a dogmatic approach from one party or the other. Veterinary professionals may be limited in knowledge, time and resources when dealing with wildlife species. The current need for all veterinarians to provide emergency care to wildlife can result in a poor quality of care being provided in some instances, much to the despair of rehabilitators.

The priority of wildlife rescue centres is often concentrated upon the care of casualties rather than record keeping. Improved records would allow the data available in these centres to be used to predict outcomes, assess the success of techniques used in treatment and rehabilitation, and ultimately improve the welfare of badgers and other wildlife whilst captive.

7.5 Summary

One third of all badger casualties survived to release, similar to figures in other studies of rehabilitated wildlife. Half the euthanased badgers were humanely destroyed following triage and clinical examination. The short time periods spent in captivity for those animals that were euthanased or died unexpectedly highlighted an effective triage process that considered badger welfare above all other concerns. This

study supports other findings that effective triage is essential for the welfare of wildlife casualties.

Medical treatments used in badgers are similar to those in domestic small animals. Consideration of the use of some drugs such as corticosteroids and opioids should be made in light of new evidence of their efficacy in other species. Orthopaedic surgery in badgers is limited for practical and ethical reasons.

Ecological factors greatly influence the reasons for presentation and outcome of badgers including; the time of year, badger ranging and territorial behaviour, and the occurrence of bite wounds. The prognosis was better for badgers found in buildings than for those found at the roadside and consequently for males rather than females. The need for efficient clinical examination was highlighted in the difference in prognosis for animals with bite wounds only compared to those with wounds and other concurrent problems.

The prognosis was better for younger badgers and those with better body condition scores; body weight was found to be a more variable parameter for prognosis. The return of a normal appetite was prolonged in many badgers but this did not influence release as badgers naturally conserve resources and are able to survive for several weeks without eating. Most badgers received medication while in captivity prescribed by veterinary staff following examination further highlighting the holistic approach to badger care in rehabilitation centres.

The potential for success of the rehabilitation process is dependent upon the provision of good rehabilitation facilities for the badgers and excellent working relationships between dedicated rehabilitation centre and veterinary staff. The true success of the rehabilitation and release process, and any negative ecological effects, cannot be fully quantified until accurate monitoring of all badger casualties becomes feasible.

Chapter 8

Summary discussion and recommendations

8.1 Introduction

This study reports why badgers were presented to a veterinary surgery and the factors that determined their release. As well as clinical considerations, ecological, ethical and political factors all had to be considered. Veterinary treatment was only part of the rehabilitation and release process; the general public finding and reporting the casualty badger and the wildlife rescue charity responsible for its care, rehabilitation and eventual release all provided their contribution to each successful case. The reasons why people became involved varied; some were concerned because they had caused or witnessed the RTA occurring, others simply because they found a badger in their garden and considered it to be a pest. The general public were sympathetic to the casualty animal they came in contact with and valued conservation in general, as has been noted by others (Bennett *et al.*, 2009).

There is undoubtedly an educational benefit to those involved in the rescue and treatment of wildlife casualties that creates an environmental and conservation awareness beyond the care of the individual animal. The treatment of non-endangered species may indeed develop skills subsequently useful when presented with endangered species or useful in other aspects of their work. Such benefits however, should never detract from the welfare of the individual casualty and while an increasing number of medical and surgical problems can be treated the animal's best interests must always be considered.

Whilst in captivity the welfare of the casualty animal, and that of those people and animals with which it is in contact, can be ensured. Once released back to the wild the health of the animal, even in the short-term, remains relatively unknown. This area of rehabilitation requires more research to ensure the welfare of casualties upon release. The wider ecological consequences of releases upon existing populations of that species and others also requires further consideration, especially when animals are translocated.

8.2 Summary of study findings

8.2.1 Demographics

The seasonality of admissions of badger casualties was influenced by their ecology, including the availability of food and territorial behaviour associated with the breeding season. These factors influenced the use of buildings and involvement in RTAs, which resulted in increased contact with man and admissions of injured or apparently debilitated animals. Male and female badgers were equally represented overall, but male badgers were commonly found in domestic and farm buildings while female badgers were more commonly involved in RTAs and there was a seasonality associated with RTAs admissions that concurred with other studies.

Members of the general public finding badger casualties were able to recognise major problems but often the animals had additional or multiple problems. Many badgers had low body weight, although seasonal effects on this parameter make it a poor indicator of prognosis. Adult badgers of all ages were presented as casualties suggesting that the reasons for presentation were not restricted to any particular age demographic.

8.2.2 Clinical findings

Bite wounds, RTA and chronic disease were the most common presenting problems. Clinical examination after sedation was an essential part of casualty assessment, with body condition score a very useful prognostic indicator. Dental disease was not a major problem although trauma to teeth, often consequent to RTA, was not an uncommon finding. The clinical value of blood test results was limited in many cases by the presence of terminal disease or multiple medical problems, together with a lack of suitable reference ranges. Radiographs confirmed the provisional diagnosis in trauma cases; clinical findings associated with RTA were similar to those found in dogs and cats.

8.2.3 Bite wounds

Bite wounds were present in over half of badger casualties and the main reason for admission in one sixth of cases. Obvious wounding was a primary observation in

badgers found in buildings, but wounds were also commonly found in RTA badgers. The high prevalence of bite wounds confirmed that such injuries are a common consequence of badger ecology. The seasonal prevalence of bite wounds was related to the badger's reproductive cycle. The distribution of bite wounds was influenced by fighting styles, with multiple wounds to head or neck in female badgers whilst males often had a single rump wound. Scars suggested frequent and repeated wounding in some individuals. Wounds varied in size, number and chronicity but were not severe enough to cause death.

The treatment of wounds in captivity, involving repeated cleaning, presents a potential zoonotic risk because *M. bovis* was cultured from some wounds. Other bacteria cultured, mostly streptococcus spp., were similar to those found in bite wounds in other wildlife species. Bite wounds healed well in captivity with topical and systemic medical treatment, but took up to 48 days. The findings of other authors that wounds appear to heal well naturally were generally supported. Welfare and legal issues influence the early release of badgers with unhealed wounds, but the consequences of protracted time in captivity remain unknown.

The prognosis for badgers with bite wounds was good if bite wounds only were present and this group represented the best prognosis for all groups of casualties. The prognosis for release was however poor if bite wounds occurred concurrently with other reasons for disability or disease, highlighting the need for thorough clinical examination under sedation.

8.2.4 Tuberculosis (*M. bovis* infection)

Some badgers admitted for rehabilitation were infected with *M. bovis* and some showed signs of clinical tuberculosis, a factor that may not have been appreciated by those involved in their care. The numbers of casualty badgers testing positive for *M. bovis* infection was not high, especially since the study population was naturally biased towards diseased and debilitated individuals, however the true prevalence of infected animals is limited by the sensitivity of available tests. The standard triage process applied to all badgers appeared to identify clinical cases and ensured that they did not spend a long time in captivity and were not released. Veterinary

clinicians are able to recognize sick diseased badgers, however a definitive diagnosis of tuberculosis in a live animal remains difficult. Biochemical and haematological tests were not specific for tuberculosis. Radiography can be used to identify lung and bone lesions that may be associated with tuberculosis. The availability of the BrockTB STAT-PAK® as a rapid badger side test and potential use of interferon gamma assays to improve test sensitivity may improve diagnosis and limit exposure to *M. bovis* in the future.

8.2.5 Treatment, rehabilitation and release

Approximately one third of the badger casualties in the study were released, consistent with other studies of wildlife casualties. A rigorous triage process resulted in most casualties unsuitable for release being euthanased for welfare reasons within the first 24 hours in captivity; few casualties died unexpectedly. This triage process was considered essential for the welfare of casualties and relied upon the badger being seen by a veterinary surgeon or trained RVN soon after admission.

The prognosis for badgers found at the roadside, often female, was poor. The prognosis for badgers with bite wounds only, often males and found in buildings, was good. Broad categorization of potentially successful release candidates was however not advocated and treatment of individual animals based upon a thorough clinical examination was considered to be the best approach. Body condition score was a better prognostic indicator than body weight, because weight varied more in association with non-clinical factors.

The medical and surgical treatments of badgers were broadly similar to dogs and cats. However, badger ecology, and the needs of a wild animal both in captivity and upon release, require some additional considerations. Orthopaedic surgery, for example, is inappropriate because it necessitates protracted time in captivity. Other developments in modern human and domestic animal medicine, such as new evidence for administration of specific drugs, must be acknowledged and incorporated into wildlife medicine. Food intake in captive badgers was variable with many badgers failing to eat for several days; initial appetite is therefore a poor prognostic indicator for release. Medication was consequently administered

parenterally in most instances. Pain relief was considered essential for rapid recovery and release.

Good observation, accurate records and constant reassessment were requirements throughout the rehabilitation process and a strong working relationship with the rescue centre was considered essential. Good medium duration care facilities are also needed with well-trained staff and adequate funding.

8.3 Recommendations

8.3.1 Education of veterinary surgeons

Currently all veterinary surgeons in the UK are required by law to provide emergency treatment to wildlife casualties. Whilst satisfying an immediate welfare concern, this system fails to consider the inability of most veterinary surgery facilities to provide suitable longer-term care for these casualties. Veterinary student education in 'exotic pets' has greatly increased over recent years but has not been accompanied by a similar increase in free-ranging wildlife education. If veterinary surgeons are required to treat wildlife casualties then better undergraduate education is required, including some study of the basic ecology of common British species.

This study has shown that full clinical examination of badger casualties by a veterinary surgeon or suitable trained RVN as part of the triage process is essential for their welfare. More published information of the principles of treating casualties and on the care of specific species would be advantageous.

In the case of badgers, an awareness of *M. bovis* infection as a zoonosis and a risk to other animals during captivity and other badgers and domestic livestock after release of casualties, is essential. It is likely however, that as a result of biased reporting in the veterinary media, most practicing veterinary surgeons would over emphasise the bTB problem in badgers and education should highlight the evidence and actual risks and how to minimise these.

Bite wounds are a common problem in badgers but their clinical presentation may cause concern for veterinary practitioners who may be unfamiliar with their

appearance. As these wounds heal well practitioners should be informed that they are not necessarily a reason for euthanasia, however a full examination is necessary to ensure concurrent problems that would negatively influence prognosis are not overlooked. Body condition score is a better guide to prognosis than weight and basic scoring techniques should be promoted and distributed to veterinary practices.

8.3.2 Education of rehabilitators

In general, wildlife rescue centres and rehabilitators carry out an excellent job in returning wildlife casualties to the wild but require well-trained staff, suitable facilities and adequate funding. There is currently no mechanism or statutory control to ensure that facilities reach an appropriate standard of care and this should be addressed if the welfare of casualty animals is to be ensured.

Training of staff at rehabilitation centers must include an awareness of zoonotic risks. In the case of badgers the risk from *M. bovis* infection must be considered and staff should be made aware of potential risks associated with cleaning wounds and disposal of waste products, as well as through obvious traumatic injury such as bites and scratches.

Wildlife rescue centres have the potential to generate large amounts of data essential in furthering our knowledge of rehabilitation and release. Appropriate data bases and accurate records should be kept.

8.3.3 Education of the general public

Education of the general public is an important part of wildlife casualty care. Over recent years charities such as the RSPCA have concentrated upon education relating to the inappropriate capture of juveniles. Education regarding what is normal in terms of behaviour and injury in adult animals is also essential. In the case of badgers large bite wounds raise genuine concern, but many animals would if left alone, return to their setts and the wounds heal unaided. RTA injuries represent the other main interface with humans and better badger warning signs on roads near setts would benefit both badger and drivers. More badger culverts under roads would additionally reduce accidents.

8.3.4 Improved clinical tests

There are currently no haematology and clinical biochemistry reference ranges from normal healthy badgers. Another survey of wild badgers, ideally in a non-bTB endemic area such as Scotland would address this lack of essential knowledge. This is unlikely to occur since most large field-study sites are in bTB endemic areas. Use of current study sites, together with input from veterinary surgeons could however improve the usefulness of the results of blood tests by considering them alongside clinical examination findings and other diagnostic aids such as urinalysis and radiography, and post-mortem examination. These data would be especially beneficial in interpreting radiographic findings such as lung and bone lesions, which are common pathological changes associated with tuberculosis. Advanced imaging techniques such as CT and MRI would also be very valuable in such investigations.

Within clinical veterinary practice urinalysis should be added to veterinary tests in an appropriately safe way to assist with the interpretation of azotaemic blood results. Radiographic chest films should be taken where possible on inspiration, or with the lungs manually inflated, however precautions must be taken to limit spread of infection via anaesthetic equipment.

8.3.5 Consideration of *M. bovis* infection

Veterinary surgeons involved in the care and rehabilitation of badgers must be abreast of new diagnostic tests for *M. bovis* infection and where possible have access to new test modalities as soon as they are developed. A clear understanding of the information that is provided by the test (infected versus clinical disease) is required together with knowledge of the test's sensitivity and specificity. As is the case for others concerned with the diagnosis of tuberculosis, new test methods that differentiate between the different stages of infection and disease are essential for our understanding of the disease process and the prevention of infection.

Concern regarding the risk of disease transmission from casualty badgers, both whilst in captivity and upon their release, needs to be based upon scientific evidence and kept proportional to the genuine risk. Political influences regarding *M. bovis* in badgers are however likely to continue to affect the rehabilitation process and these

too must be given appropriate regard if the process is to maintain credibility with farmers and other concerned groups.

8.3.6 Improved monitoring post-release

Post-release monitoring is essential to assess the true success of rehabilitation and release. Unfortunately, there are no data on the short or longer-term outcomes of rehabilitation for most casualties so their welfare cannot be assured. In badgers an emphasis has been put on bTB, but release and translocation of animals may have other ecological, genetic and disease influences and further study into these areas are essential.

8.4 Concluding comments

There is little doubt than an increasingly environmentally aware general public will continue to present sick and injured wildlife species, including badgers, for veterinary treatment. However, the expectations of concerned finders are outweighed by the welfare of the individual animal and risks to humans and other animals. If the veterinary profession is to satisfy the required welfare and public need it must deal with wildlife professionally in an informed and evidence-based manner. Veterinary surgeons must realise that full clinical assessment and good quality veterinary medicine are essential parts of wildlife treatment in partnership with a well funded, equipped and skilled rehabilitation facility. The effects of badger releases need to be investigated further to ensure the welfare of individual badgers upon release and the welfare of populations, both of badgers and of other contact species. Veterinarians may not necessarily have all the skills to deal with the ecological, ethical and political issues that influence wildlife rehabilitation and release and must seek collaborative help from colleagues elsewhere. Modern wildlife disease management requires 'a multidisciplinary approach involving ecologists, epidemiologists, experts in public health, mathematical modellers, geographic information specialists, statisticians and economists' (Delahay *et al.*, 2009). There is a role for veterinarians within this necessary broad range of specialists, where clinical expertise is an important part of understanding disease processes and their significance to affected animals and in contacts.

Appendix 1

Record sheets

Appendix 1.1

QUANTOCK VETERINARY HOSPITAL BADGER RECORD SHEET

(* see appendix number as indicated)

Secret world log No.

ID chip No.

RSPCA log No.

Tattoo No.

History (*1):

Admission date:

Body length (*1) (mm):

Weight (Kg):

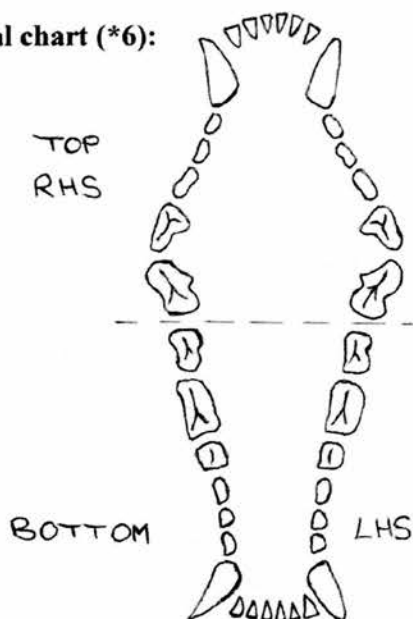
Age (*2): Cub / Adult

Sex: M / F

Condition (*3): Poor / Fair / Good / V.good

Female (*4): Lactating / L. this year / Pregnant / L.sometime / never / unsure

Dental chart (*6):



Dental formula:

Adult: I 3/3, C 1/1, PM 4/4, M 1/2 = 38

Cub: I 3/3, C 1/1, PM 4/4, M 0/0 = 32

X missing
T temporary
V vestigial
fractured

Tooth wear (*6): 0 1/4 1/2 3/4 1

Comments:

Bite wounds: Present / None

Number and distribution (*7):

		Head	Neck	Rump	Limb	Body	Inguinal
No.	One						
	Few (1-2)						
	Lots (>3)						
Age	Open (fresh)						
	Open (old)						
	Healed (scar)						
Size	Small (puncture)						
	Medium (gash)						
	Large (gaping)						

Bite wounds swabbed (charcoal) []

Blood collected (heparin, EDTA, serum) []

Radiographs taken (DV) []

Clinical summary:

Treatment given:

Outcome (today):

Released Hospitalised Rehabilitated Euthanased Died

Outcome longterm (date):

Released Hospitalised Rehabilitated Euthanased Died

Appendix 1.1.1

Guidance notes for QVH staff to support badger record sheet

Note 1: Badger history and length measurement

a) History:

Please include:

- i) Where found geographically: grid reference or exact position in specified village, road etc., this will have been recorded by Secret World in order to release the badger back to the exact place where it was found.
- ii) Where found / what type of place: e.g. field, wood, building, garden, roadside
- iii) Why presented / finders presenting signs: e.g. RTA, dead, trapped, snared, shot, wounds
- iv) Notes on initial clinical presentation: e.g. collapsed, bleeding

b) Body length:

Place sedated / anaethetised badger onto dorsum and measure with the spine as straight as possible. Measure midline from tip of nose to final tail vertebra. Record the measurement in millimetres.

Appendix 1.1.2

Guidance notes for QVH staff to support badger record sheet

Note 2: Badger age class determination

Badgers are recorded as either a cub or an adult. Age class is determined by the following combination of features:

Cubs

- Smaller
- Fluffy coat with clean contrasting colours
- Narrower and more pointed head
- Milk teeth may be present upto 16 weeks
- Negligible tooth wear

Adults

- Larger
- Broad and muscular head
- Tooth wear evident

Based on record sheet information from FERA Woodchester Park

Appendix 1.1.3

Guidance notes for QVH staff to support badger record sheet

Note 3: Badger body conditions assessment

Body condition is recorded on a four-point scale by visual and tactile examination. The body condition is determined by the following combination of features:

Poor

- The shoulder blades, pelvic region, ribs and vertebrae are prominent to touch
- Starry coat

Fair

- The pelvic region and shoulder blades are not as prominent to touch
- There is more musculature covering the shoulder blades and pelvic region

Good

- Good musculature covering the entire body of the badger especially the shoulder blades and pelvic region.

Very Good

- A layer of subcutaneous fat over the entire body especially in the lower abdominal region and scruff of the neck.
- The pelvic region and shoulder blades well covered.

Based on record sheet information from FERA Woodchester Park

Appendix 1.1.4

Guidance notes for QVH staff to support badger record sheet

Note 4: Badger reproductive condition assessment

Lactating females

During lactation the teats become enlarged and the surrounding hair wears thin. The teats of suckling females are always bigger than those of non-lactating females. Milk can be expressed by squeezing the teat at the base and massaging your fingers upwards. After the young are weaned, the nipples harden, reduce in size and darken, and some hair grows back. However, they are still distinguishable from the smaller, paler teats of badgers that have never suckled.

Pregnant females

A pregnant female is recognised by the characteristic swelling of the abdomen, particularly during the later stages. It is possible to feel the embryos by gentle palpation.

Males

In immature males the testes are small and held inside the abdomen. At maturation or onset of breeding the testes enlarge and descend into the scrotal sac. Weights of paired testicles in mature males reach a mean maximum of 11g in February-March, decreasing slowly to a mean minimum of 5g in October-November. Testes are classed as ascended if they are held inside the abdomen, as descended if in the scrotal sac and mid if between these two positions.

Based on record sheet information from FERA Woodchester Park

Appendix 1.1.5

Guidance notes for QVH staff to support badger record sheet

Note 5: Dental chart

Dental formula for badgers, temporary dentition in brackets:

	3 (3)		1 (1)		4 (4)		1 (0)	
Incisors	-	Canines	-	Premolars	-	Molars	-	= 38 (32)
	3 (3)		1 (1)		4 (4)		2 (0)	

The incisors, canines and first premolar are similar to those of dogs. The first premolar may be either vestigial or absent. The last premolar and molars are broad, flat and multicuspid (see appendix 6 for recording tooth wear).

In cubs incisors 1 and 2 may not penetrate the gum and premolar 1 may be absent, shed early or not penetrate the gum.

Please indicate on the dental chart if teeth are:

X	missing
T	temporary
V	vestigial
#	fractured

Tooth wear is assessed using the Woodchester Park scoring system as described in Note 6.

Appendix 1.1.6

Guidance notes for QVH staff to support badger record sheet

Note 6: Badger tooth wear assessment

Tooth wear in badgers is recorded to give an indication of the age and condition of an individual. It is recorded as a score on a 5 point descriptive scale, based on wear to the incisors and the cusps of the molars.

The categories

- '0' – No tooth wear. This applies to cubs only. Incisors are tricuspid with sharp edges. Upper molars have 5 clear cusps, lower molars have 6 clear cusps.
- '0.25' – 25% wear. Badgers usually only show this amount of tooth wear in their second year. Incisors are no longer tricuspid and molars no longer have clearly defined cusps, they will be worn flat across the tips but tooth height will not have been significantly reduced.
- '0.5' – 50% wear. The flattened area of the incisors and molars will be much more conspicuous than in the previous category as it extends into the broadening section of the tooth. Tooth height will have been reduced by 25-50%.
- '0.75' – 75% wear. Wear to incisors and molars will have reduced tooth height by 50-80%. Very flat cusps.
- '1' – 100% wear. The teeth have been worn down close to or level with the gums and tooth height is consequently reduced by more than 80%. No cusps visible.

Based on record sheet information from FERA Woodchester Park

Appendix 1.1.7

Guidance notes for QVH staff to support badger record sheet

Note 7: Badger bite wound assessment

Please class wounds in three ways in the table given:

- i) Number of wounds
- ii) Open or Healed or Scar*
- iii) Size

If there is more than one wound, indicate the number of each type in sections ii) and iii);

For example:

		Head	Neck	Rump	Limb	Body	Inguinal
	One			1			
i)	Few (2-3)	2					
	Lots (>3)						
	Open (fresh)	1					
ii)	Open (old)	1		1			
	Healed (scar)						
	Small (puncture)	2					
iii)	Medium (gash)						
	Large (gaping)			1			

*

- Fresh bite wound: localised swelling, oedema, bleeding, blood matted on hair
- Old bite wound: bacterial infection, scab formation, dry wound margins, granulation tissue
- Scar tissue: localised fibrous tissue

Based on record sheet information from FERA Woodchester Park

Appendix 1.2

Example QVH hospitalisation record

QUANTOCK VETERINARY HOSPITAL – INTENSIVE CARE RECORD									
ANIMAL: <u>Badger</u>		CLIENT: <u>S. Jorid</u>		REF. NO: <u>EM 63</u>		VET: <u>LM</u>		DATE: <u>25.3.05</u>	
SPECIES:		BREED:		SEX: <u>F</u>		AGE: <u>young</u>		WEIGHT: <u>5.2 kg</u>	
REASON FOR STAY: <u>RTA</u> <u>Dehydrated</u>									

CLINICAL PARAMETERS					PATIENT MANAGEMENT				
Time	1.00	4.30	8.00	10.30		Time	4.30	10.30	
Demcan.	<u>flr</u>	<u>Quiet</u>	<u>Quiet</u>	<u>Quiet</u>	<u>Died</u>	Fed	<u>/</u>	<u>P</u>	<u>Died</u>
Temp.						Ate	<u>/</u>	<u>→</u>	
Pulse						Water	<u>/</u>	<u>300 ml</u>	
RR	<u>40</u>	<u>30</u>	<u>32</u>	<u>40</u>		Drank	<u>/</u>	<u>→</u>	
MMm	<u>/</u>	<u>/</u>	<u>/</u>	<u>/</u>		Vomit	<u>x</u>	<u>x</u>	
CRT	<u>/</u>	<u>/</u>	<u>/</u>	<u>/</u>		Urine	<u>x</u>	<u>x</u>	
% Deh.	<u>++</u>	<u>++</u>	<u>++</u>	<u>++</u>		Faeces	<u>x</u>	<u>✓</u>	
Pain sc.	<u>+</u>	<u>+</u>	<u>+</u>	<u>+</u>		Catheter	<u>✓</u>	<u>✓</u>	
	<u>SE</u>	<u>SE</u>	<u>SE</u>	<u>SE</u>		Walked	<u>N/A</u>	<u>N/A</u>	
							<u>SE</u>	<u>SE</u>	

MEDICATION	DOSE	ROUTE	FREQ.	TREATMENT RECORD					
<u>metacam</u>	<u>0.25ml</u>	<u>i/v</u>	<u>sid</u>	<u>1.00</u>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
					<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
					<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
					<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
					<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
					<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

FLUID THERAPY:			1:3 for first 50 ml	
FLUID TYPE:	<u>Hartmann's</u>	RATE:	<u>Then ↓ to 1:5</u>	ADDITIONS
				<u>x</u>

BURETTE MANAGEMENT							
Time	Burette Vol.	Vol. Added	New Level	Time	Burette Vol.	Vol. Added	New Level
<u>1.00</u>	<u>130 ml</u>	<u>-</u>	<u>130 ml</u>	<u>10.30</u>	<u>-</u>	<u>150 ml</u>	<u>150 ml</u>
<u>3.00</u>	<u>100 ml</u>	<u>-</u>	<u>100 ml</u>				
<u>6.00</u>	<u>80 ml</u>	<u>-</u>	<u>80 ml</u>				
<u>8.30</u>	<u>0 ml</u>	<u>80 ml</u>	<u>80 ml</u>				

* Δ to Hartmann's.

Appendix 1.3

Example SWWR hospitalisation record

Pen/cage No: 01A
 Sheet No: 1
 Species: Badger
 Log number: 5886
 Sex: male
 Date of birth: 01/05/05
 Location: Large T. Rump Wound
 Treatment: Intravital injection SIC Sid for 7-10 days
 Log number: 5886
 Sex: male

Date	Weight	Time Feed & Content	Amount Taken	Urine	Faeces	Medication	Comments
01/05		AM: left H2O PM: 1 x B. portion	N/A	X	X		Lisa can Sedate examine on Friday
6/10		AM: Cleaned + left 1 x portion + W PM: Cleaned 3 left water	Chicks + SHENIES All gone		None		
7/10		AM: left 1 x portion PM: Cleaned + left fresh water		✓	✓	1/2	Sedated tattoo frontlined SB/3005 Ticks + + +
8/10		AM: Cleaned + left fresh water PM: left 1 x B. portion	Food gone	✓	✓	1/2	Always from heat - tonnes light off
9/10		AM: Cleaned out PM: left fresh H2O HBAB	all gone except strawberries	✓	✓	1/2	Cleaned wound with hibi scrub. elise USA.
10/10		AM: Cleaned out left fresh H2O PM: left 1 x portion	all gone	✓	✓	1/2	wound looking good. fresh blood coming through nicely
11/10		AM: Cleaned/water PM: left 1 x portion	All gone	✓	✓	1/2	em+ewe

Sheet Ref: AC001

Appendix 1.4

Clinical summary sheet

Reference number:

Summary of reasons for admission:

Findings on examination:

i) Examination:

ii) Blood tests:

ii) Radiographs

ii) Summary of findings

Reasoning for outcomes:

i) Treatment:

ii) Outcome:

Appendix 1.5

Radiographic interpretation sheet

Reference number:

Date taken:

View(s)

Lateral:

DV:

VD:

Radiographic check list: circle body parts(s) considered abnormal:

- | | |
|--------------|------------------|
| 10 Skull | 11 Mandible |
| | 12 Maxilla |
| 20 Spine | 21 Cervical |
| | 22 Thoracic |
| | 23 Lumbar |
| | 24 Sacral |
| | 25 Coccigeal |
| 30 Ribs | |
| 40 Fore limb | 41 Shoulder |
| | 42 Humerus |
| | 43 Elbow |
| | 44 Radius / ulna |
| | 45 Carpus |
| | 46 Fore Digits |
| 50 Pelvis | 51 Ischium |
| | 52 Ileum |
| | 53 Pubis |
| | 54 Hip |
| 60 Hindlimb | 61 Femur |

62 Stifle

63 Tibia / fibula

64 Tarsus

65 Hind digits

70 Abdomen 71 Liver

72 Spleen

73 Uterus

74 Gut

75 Peritoneum

80 Thorax 81 Lungs

82 Heart

83 Pleura

Description of radiographic abnormalities seen:

Classification of abnormality seen (circle):

1 Fracture

2 Dislocation

3 Bone lysis or proliferation

4 Abnormal Radiodensity

5 Abnormal Radiolucency

6 Swelling

Significance of radiographic changes in relation to treatment and outcome:

Appendix 2

Supporting material used in the clinical study

Appendix 2.1

WOODCHESTER PARK SAMPLING SHEET



TATT.

DATE

SERUM NO.

M.O.C. : trap RTA fnd dead fnd extr net snare shot

RECORDER

SOCIAL GROUP

SETT NAME

IF OTHER : field wood hedge bdy bldg gdn outside WP

NAME

BODY LENGTH mm

WEIGHT Kg

AGE : CUB ADULT

SEX : MALE FEM.

MALE : ASCND. MID DESCN

FEMALE : LACT LACT THIS YR PREG L. SOMETIME NEVER UNSURE

CONDITION : POOR FAIR GOOD VG

BITE WOUNDS

NONE

	HEAD	NECK	RUMP	LIMB	BODY	INGUI.
ONE	✓		✓		✓	
FEW (2 or 3)					✓	
LOTS (>3)						
OPEN (fresh)	✓		✓		✓①	
OPEN (old)						
HEALED (scar)					✓②	
SML (puncture)						
MED (gash)	✓		✓		✓①	
LGE (gaping)					✓②	

TRANSMITTER

FITTED PRES LOST

REPLCD REMVD

TX No

BEST TUNE

P.P.M.

TOOTHWEAR : 0 $\frac{1}{4}$ $\frac{1}{2}$ $\frac{3}{4}$ 1

	✓ / O	Initial	AF. No.	RESULTS
TA	✓			
URINE	✓			
FAECES	O			
ELISA				
L SUBM				
R SUBM				
HEAD				
NECK				
BODY				
RUMP				

TEMP. °C

BLOOD

No. of tubes taken

Initial: R.D.

Red Green Purple

☐ ☐ ☐

DATE

SIGNED

MRCVS

COMMENTS

FURCLIP

Appendix 2.2

Example Vettest® biochemistry and electrolyte results

EM65

QUANTOCK VETERINARY HOSPITAL
CHEETHAM HOUSE
THE DROVE
BRIDGWATER

Species : Other
Patient : 0
Client : Badger- Bluebell 3918

Ver: 8.02A
Date : 08-Apr -2005 10:42

Test	Results	Reference Range	Indicator		
			LOW	NORMAL	HIGH
ALB	= 24 g/l	~			
ALKP	= 62 U/L	~			
ALT	= 60 U/L	~			
AMYL	= 220 U/L	L			
UREA	= 10.47 mmol/l	H			
Ca	= 2.18 mmol/l	~			
CHOL	= 4.00 mmol/l	~			
CREA	= 56 umol/l	~			
GLU	= 9.77 mmol/l	H			
PHOS	= 1.97 mmol/l	~			
TBIL	= 8 umol/l	~			
TP	= 74 g/l	~			
GLOB	= 50 g/l	H			
Na	= 154.1 mmol/l	~			
K	= 4.51 mmol/l	~			
Cl	= 116.0 mmol/l	~			

Appendix 2.3

Example Idexx QA results



IDEXX LABORATORIES
GRANGE HOUSE
SANDBECK WAY
WETHERBY
WEST YORKSHIRE Tel : 01937 544000
LS22 4DN Fax : 01937 544001

LizMullineaux
 Quantock Veterinary Hospital
 The Drove
 Bridgewater
 TA6 4BA

VETTEST EQAS C127
Survey Reference Number 6.2

<u>Analyte</u>	<u>Optics Grp</u>	<u>Your Val</u>	<u>Mean</u>	<u>Comment</u>
ALT	4	55	49.17	Good
ALBUMIN	3	44	42.62	Good
ALP	5	178	169.30	Good
AMY	2	89	91.33	Good
BILI	2	19	23.04	Good
BUN	3	7.85	7.74	Good
CALCIUM	6	2.37	2.33	Good
CHOL	2	4.42	4.73	Good
CREAT	3	165	178.05	Good
GLUC	2	6.31	6.67	Good
PHOS	3	1.37	1.45	Good
PROT	2	62	61.95	Good
SODIUM	Elec	148.9	147.03	Good
POTASSIUM	Elec	4.23	4.38	Good
CHLORIDE	Elec	106.5	104.92	Good

Appendix 2.4

Correction of plasma calcium

The protein bound part of total serum calcium concentrations may be influenced by plasma protein concentrations, in particular albumin.

Correction of total plasma calcium concentrations for albumin concentrations was carried out using the following formula (Bush, 1991)

$$\text{Corrected Ca} = \text{Measured Ca (mmol/l)} - \frac{\text{Albumin (g/l)}}{40} + 0.875$$

Appendix 2.5

Example Idexx haematology results

Laboratory Address:
PO Box 4 Wetherby
West Yorkshire LS22 4YY
Telephone (01937) 544000
Fax (01937) 544001



Invoice Address:
Milton Court Churchfield Road
Chalfont St Peter Bucks SL9 9EW
Telephone (01753) 891660
Fax (01753) 891520

Ref No : 0668758 (Page 1/1)

L MULLINEAUX
QUANTOCK VETERINARY HOSPITAL
CHEETHAM HOUSE
THE DROVE, BRIDGEWATER
SOMERSET
TA6 4BA

Owner / Animal
{3918}, BADGER

Species : BADGER
A/C Code : C127
Fax No : 0127 844 4963
Tel No : 0127 845 0080

HAEMATOLOGY Full Blood Count

Red cells	7.85	10 ¹² /l	2	2
Haemoglobin	11.8	g/dl		
Hct	0.362	l/l	1	2
MCV	46.1	fl	1	2
MCH	15.0	pg	1	2
MCHC	32.6	g/dl	2	2
Red Cell Distribution Width	16.1	%	2	2
White Cells	10.5	10 ⁹ /l		
Neutrophils	78% 8.19	10 ⁹ /l	2	2
Lymphocytes	13% 1.37	10 ⁹ /l	2	2
Monocytes	9% 0.95	10 ⁹ /l	2	2
Eosinophils	0% 0.00	10 ⁹ /l	2	2
Platelet count	398	10 ⁹ /l	2	2

Morphological Assessment : Red cells appear normal.
No abnormal white cells seen.

COMMENT

Claire G. Crompton BVSc MRCVS
Clinical Pathologist/Microbiologist.

Reference No : 0668758
Total request fee : £ 13.00 plus VAT

Date Reported : 09/04/05
Date Received : 09/04/05

The above fee is inclusive of all tests requested under this reference number. *This is not a VAT invoice*

Where applicable * denotes result outside reference range
Please see IDEXX website (www.idexx.co.uk/ukas) for details of Test Methods.

Appendix 2.6

Reference intervals and ranges

Parameter	Units	Canine reference intervals Vettest™	Canine reference intervals Idexx Labs.	Badger reference ranges Woodchester Park (Mullineaux, 2003)
Biochemistry				
ALKP	U/l	23-212	-	0-192.45
ALT	U/l	10-100	-	0-232.31
AMYL	U/l	500-1500	-	-
UREA	mmol/l	2.5-9.6	-	2.87-11.15
Ca	mmol/l	1.98-3.00	-	2.01-2.54
CHOL	mmol/l	2.84-8.27	-	2.82-8.49
CREA	umol/l	44-159	-	68.39-121.12
GLU	mmol/l	4.11-7.94	-	-
PHOS	mmol/l	0.81-2.19	-	-
TBIL	umol/l	0-15	-	0.71-9.13
TP	g/l	52-82	-	55.03-73.81
GLOB	g/l	25-45	-	21.13-34.50
ALB	g/l	23-40	-	30.82-42.29
Electrolytes				
Na	mmol/l	144-160	-	-
K	mmol/l	3.5-5.8	-	-
Cl	mmol/l	109-122	-	-
Haematology				
Red Cells	$\times 10^{12}/l$	-	5.5-8.5	6.93-12.99
Haemoglobin	g/dl	-	12.0-18.0	10.73-19.12
Hct	%	-	38.0-57.0	30.09-53.23
MCV	fl	-	61.0-80.0	38.05-45.71
MCH	pg	-	20.0-26.0	13.79-16.14
MCHC	g/dl	-	30.0-36.0	33.55-37.95
Red Cell distrib. width	%	-	10.0-16.0	19.11-24.14
White Cells	$\times 10^9/l$	-	6.0-15.0	2.56-10.36
Neutrophils	$\times 10^9/l$	-	2.5-12.5	1.07-8.27
Lymphocytes	$\times 10^9/l$	-	0.5-4.8	0.09-2.66
Monocytes	$\times 10^9/l$	-	<0.8	0-9.66
Eosinophils	$\times 10^9/l$	-	0.05-0.8	0-0.33
Platelet count	$\times 10^9/l$	-	150.0-450.0	279.36-817.45

Appendix 2.7

SWWR treatment of badger bite wounds

Bite wounds in badgers generally require only cleaning and surface treatment rather than stitching or wound dressings. The following protocol should be followed for wounds on admission.

Day one

- Sedate badgers (vet or RVN under vet direction)
- Examine badger all over for evidence of wounds (usually rump, head and neck, but check other areas carefully too).
- Clip any areas of matted hair that would be difficult to clean, however KEEP CLIPPING TO A MINIMUM as we do not want excessive clipping and waiting for hair re-growth to be a reason for keeping the badger for longer in captivity.
- Clean away any surface scabs and debris using dilute chlorhexidine scrub and surgical swabs. Remove as much debris as is possible, do not worry about the wound surface and edges bleeding a little.
- Once clean flush the surface and any pockets with sterile saline and dry off with sterile swabs.
- Pack any pockets with 'Intrasite gel'.
- Give any medication prescribed by the vet whilst the badger is still sedated.
- Reverse the sedative drugs.

Subsequent days

- If the wound(s) can be safely cleaned without sedation (usually rump wounds), then restrain and treat wounds daily.
 - Clean the surface of the wound with dilute chlorhexidine using swabs.
 - Pack any pockets with Intrasite gel.
 - Continue daily cleaning until the wounds are becoming scars and less raw tissue is exposed.
 - Continue any daily medications prescribed by the vet
 - Seek supervisor's advice on when the badger can be released.
 - Ensure badgers are tattooed before release.
- If the wounds are in areas that cannot be cleaned daily (usually head wounds), then check the wounds daily and if necessary book an appointment for the wounds to be re cleaned every 3-4 days.
- If you are unsure about the progress of the wound healing at any point speak to your supervisor or contact the vets.

Appendix 2.8

Reference ranges for haematology and haematochemistry for *Meles meles* from research animals at the Veterinary Laboratories Agency

Parameter	Unit	Min	Max
WBC	$\times 10^9/l$	2.56	10.36
Neutrophils	$\times 10^9/l$	1.07	8.27
Neutrophils	%	50.49	92.32
Lymphocytes	$\times 10^9/l$	0.09	2.66
Lymphocytes	%	2.96	41.04
Monocytes	$\times 10^9/l$	0.00	0.63
Monocytes	%	0.00	9.66
Eosinophils	$\times 10^9/l$	0.00	0.33
Eosinophils	%	0.00	5.11
Basophils	$\times 10^9/l$	0.00	0.15
Basophils	%	0.00	2.23
RBC	$\times 10^{12}/l$	6.93	12.99
HGB	g/dL	10.73	19.12
HCT	%	30.09	53.23
MCV	fL	38.05	45.71
MCH	pg	13.79	16.14
MCHC	g/dL	33.55	37.95
RDW	%	19.11	24.14
PLT	$\times 10^9/l$	279.36	817.45
Total protein	g/l	55.03	73.81
Albumin	g/l	30.82	42.39
Globulin	g/l	21.13	34.50
Calcium	mmol/l	2.01	2.54
Magnesium	mmol/l	0.62	1.13
Urea	mmol/l	2.87	11.15
Creatinine	umol/l	68.39	121.12
Cholesterol	mmol/l	2.82	8.49
Bilirubin	umol/l	0.71	9.13
ALT	U/l	0.00	232.31
GGT	U/l	1.02	4.32
ALP	U/l	0.00	192.45
Cortisol	nmol/l	0.00	264.20

Courtesy of Dr Sandrine Lesellier, TB Research Group, Department of Statutory and Exotic Bacterial Diseases, Veterinary Laboratories Agency, Weybridge.

Appendix 3

Publications and presentations associated with this thesis

Part of the work in this thesis has been presented in the following oral communications, posters and journal publications:

Oral Presentations

Tuberculosis (*M. bovis*) infection in wild badgers (*Meles meles*) presented at a Veterinary Hospital. Association for Veterinary Teaching and Research Work, 61st Annual Meeting, Scarborough, UK, 2007. - Awarded a presidents prize.

Some facts on the consideration of *M. bovis* in the Rehabilitation and Release of Badgers (*Meles meles*). British Cattle Veterinary Association Conference, Glasgow, UK, 2007.

The diagnosis of *M. bovis* infection in badger (*Meles meles*) orphans presented for rehabilitation and release. Association for Veterinary Teaching and Research Work, 62nd Annual Meeting, Scarborough, UK, 2008.

Territorial wounding in badgers (*Meles meles*) presented to a Veterinary Hospital (2003-2006). British Small Animal Veterinary Association Congress, Birmingham, UK, 2008.

Reasons for the presentation of badger (*Meles meles*) casualties to a Veterinary Hospital. British Small Animal Veterinary Association Congress, Birmingham, UK, 2009.

Managing public demand for badger rehabilitation in an area of England with endemic tuberculosis. Fifth *M. bovis* Conference, Wellington, New Zealand, 2009.

Outcomes for adult badgers (*Meles meles*) following admission to a Veterinary Hospital and wildlife rehabilitation centre. British Small Animal Veterinary Association Congress, Birmingham, UK, 2010.

Poster presentations

The influence of potential *M. bovis* infection on the rehabilitation and release of badger (*Meles meles*) casualties and orphans. Ecology and Management of Wildlife Diseases Conference, Central Science Laboratory, York, UK, 2007.

Reasons for the presentation of badger (*Meles meles*) casualties to a Veterinary Hospital and outcomes following treatment. European Wildlife Disease Association Conference, Rovinj, Croatia, 2008.

Mycobacterium bovis in badgers (*Meles meles*) presented to a veterinary surgery and wildlife rehabilitation centre in England; controlling the risk to cattle. 26th World Buiatrics Congress, Santiago, Chile, 2010.

Journal publications

Managing Public Demand For Badger Rehabilitation In An Area Of England With Endemic Tuberculosis. Veterinary Microbiology, accepted for publication 2010.

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